Improving Operations at the San Felipe Wastewater Treatment Plant

An Interactive Qualifying Project Submitted to the Faculty of WORCESTER POLYTECHNIC INSTITUTE in partial fulfillment of the requirements for the Degree of Bachelor of Science

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Abstract

Wastewater treatment plants (WWTPs) around the world take in, treat, and release millions of gallons of water every day. Their effectiveness and efficiency is critical to ensuring all the waste does not end up in our rivers, lakes, and ultimately oceans. In this project, we worked with Souder, Miller and Associates (SMA) to evaluate the operations at the San Felipe WWTP and recommend improvements. The team evaluated the plant's data collection systems, sensors and control devices, and overall operation and maintenance procedures. We created a new data collection system used to collect and verify data reported by sensors at the plant. In a strategic plan we developed, we make recommendations regarding the operations and include ideas for future investments.

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Executive Summary

Wastewater treatment plants (WWTP) are integral in our society. Without them, harmful waste would be released into the waterways and pose health risks to the public. To ensure proper operation, data is collected and analyzed by sensors and control systems. Certain types of software tools, such as Supervisory Control and Data Acquisition (SCADA), are used in the operations of WWTPs. Many WWTPs use inefficient devices that have surpassed their expected lifetimes. Inefficient WWTPs may improperly discharge pollutants, such as metals, oils, and grease, into waterways than contain high levels of nitrogen. This is a threat to the overall water quality and human health (EPA, 2018). Outdated control systems require higher energy usage, resulting in higher operating costs that can negatively impact a treatment plant (Lobo, 2017).

Many old SCADA systems face significant setbacks, such as higher operation costs and restricted software (R.F. Wireless World 2012). Newer plants have been built using the internet of things (IoT) technology, which is the connection of physical devices to the internet (Meola, 2016). IoT can connect all of the devices on the plant floor to a single cloud-based network. The use of IoT in industrial processes, such as manufacturing, is referred to as Industrial Internet of Things (IIoT) (Rouse & Aberle, 2015).

Souder, Miller and Associates (SMA), a civil engineering firm in Santa Fe, NM, took control of wastewater operations at the San Felipe Pueblo in 2017 (SMA Operations LLC, 2018). Prior to the acquisition, the plant had been operated inadequately. With this project, we intended to assist SMA in the development of strategies that can be used to improve operations at the San Felipe WWTP.

Project Goals and Objectives

The goal of this project was to assist Souder, Miller and Associates in the development of strategies that can be used to improve operations at the San Felipe WWTP. This goal was achieved by completing two objectives. The objectives were to:

1. Create a data collection system for operators of the treatment plant.
2. Create a strategic plan to guide future operations at the San Felipe WWTP.

Methods

Create a Data Collection System

To allow operators to quickly and accurately collect data from devices around the plant, we developed a data collection form using an app called Survey123, which is a data collection system based on forms, or surveys, that provide a simple user interface to gather data (Esri, 2018). For each device at the plant, we created a QR code containing the name of the device. The QR codes are to be placed on the devices at the plant so that plant operators can easily identify devices, using the QR code reader built in to the form. We tested the form's user interface by allowing students to use the form to collect data, and used their feedback to improve the form.

Create a Strategic Plan

We created a strategic plan for the operators at the San Felipe WWTP. The plan will assist the plant operators in determining the future actions of the plant. In the plan, we describe changes to the operations and include ideas for future investments. These next sections discuss how we determined what should be in the strategic plan.

In order to create this plan, we consulted a variety of sources and contacted many people in the wastewater and IoT industries. We conducted many interviews with our liaison, John di Ruggiero, to determine the current state of the plant, allowing us to determine which areas of operation needed to be improved. After determining which operations needed improvement, we interviewed Gene Salazar and Efron Morales from the Taos and Santa Fe WWTPs, respectively, to determine how other plants conducted these operations.

We also consulted the strategic plans of the Jackson, MS; Shelby, NC; and Newberg, OR WWTPs. We did so to determine how these WWTPs incorporated operating procedures, maintenance schedules, and inventories into their strategic plans. Consulting these plans also gave us a general understanding of the formatting and content found in a strategic plan.

In order to create a strategic plan, we needed to create an inventory of the devices at the plant. Our liaison was able to provide us with a list that contained the types of devices at the plant and the manufacturer of each device. The list did not, however, include model or serial numbers. In order to determine which models were used at the plant, as well as to determine the retail price of the device or a similar model, we contacted each manufacturer by email. Any manufacturer that did not reply to our emails was called.

We also contacted experts in the IoT industry to determine how IoT could be implemented in a WWTP. We called Alan Rogers from SKM, a wastewater operations firm that partnered with SMA, to determine how they use IoT in the operations of their plants. We also contacted Opto22 and Temboo, which are both companies that provide IoT solutions for SCADA systems, to learn how their products could be used at the San Felipe plant.

Results

Create a Data Collection System

Using Survey123, we created a data collection system for the San Felipe WWTP. The form, seen in Figure A, allows plant operators to collect data from each device on the plant floor, and pins the location where each reading was taken onto a map. The form contains a QR code scanner that allows operators to read the QR code imbedded on each device. This allows operators to easily identify devices, ensuring that the readings from a device are recorded in the correct section of the form. The form also contains a comments section where operators may record any additional information regarding the state of the plant, such as a leak or malfunctioning equipment.

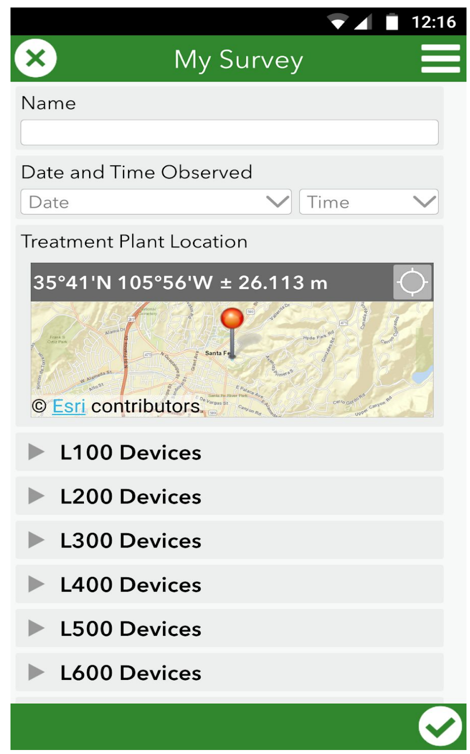

Figure A: Screenshot of Survey123 form

Our tests conducted with WPI students showed us that the form needed to be updated for user-friendliness. The most commonly suggested changes were to simplify the names of devices, to clearly identify each device on the form, and to add an instructions section. We used this information to make our form more user-friendly.

Create a Strategic Plan

From our interviews with our liaison, we found that the plant has suffered from a general lack of maintenance, and that many of the devices at the plant have started to malfunction. In particular, at 12 years old, the PLC has passed its recommended service life of 10 years and many of its components have been corroded (di Ruggiero, personal communication).

In order to determine how other plants addressed the issues facing the San Felipe plant, we interviewed plant supervisors at the Taos and Santa Fe WWTPs. From these interviews we determined that proactive maintenance and stringent operator training are key to the success of WWTPs. Both supervisors provided us with specific strategies for improving training, maintenance, and operations at the San Felipe plant.

From the strategic plans of the Jackson, MS; Shelby, NC; and Newberg, OR WWTPs, we were able to determine how a strategic plan for a WWTP should be created. We also learned how these plants organize and manage maintenance and assets. The plant in Jackson uses eRPortal, which is a computer program that assists in managing and organizing maintenance (Harrington, et al., 2014). The plant in Shelby, NC tracks all repairs through the work order forms submitted anytime an operator needs to replace or repair a device using a computer program known as Fiix (Turner, 2002).

In order to create an inventory of devices for our strategic plan, we contacted the manufacturer of every device at the plant. After doing so, we were able to determine a model number for nearly every device, as well as a replacement price, or, if the device is no longer in production, an alternative model and its price. Some of the manufacturers were unable to provide us with information because we were unable to obtain certain specifications from our sponsor.

We contacted Alan Rogers at SKM to determine the applications of IoT in WWTPs. Mr. Rogers told us that SKM predominantly uses IoT for data collection and analysis through the PLC and SCADA. He said that the use Iot has allowed not only the operators, but also the engineers at SKM to collect more data. Mr. Rogers said that more data allows a plant to run more efficiently, saving money on power, chemicals, and repairs. For San Felipe, Mr. Rogers recommended that the plant upgrade their hardware to newer, digital equipment.

We contacted IoT solutions companies, Opto22 and Temboo, to determine how IoT could be used in the San Felipe WWTP. Both companies provide IoT solutions for SCADA that include data visualization and alerts. We spoke to Kyle Orman, an engineer at Opto22, and learned about their product Groov EPIC. Groov EPIC is a web-browser based controller that connects to devices at the “edge” of the network, such sensors and meters, through Ignition Edge SCADA (Orman, personal communication). Groov EPIC can be used for all of the functions of a PLC, as well as for remote data visualization and alerts. We also contacted Temboo and spoke with sales representative, Matt Plaks. The sales representative recommended that the San Felipe plant use their Data Visualization App for SCADA. Temboo’s Data Visualization App for SCADA is a web-based software that allows users to remotely view and visualize data. The app also sends alerts via SMS text message (Plaks, personal communication). It can be used with any PLC, but Temboo recommends that it be used with the Siemens S7.

Conclusion

Based on the research conducted throughout the course of this project, we believe that the San Felipe WWTP would benefit greatly by adopting our Survey123 data collection system and the policies described in our strategic plan. Our group believes that the San Felipe plant does not operate at an optimal level of efficiency. We believe that our recommendations will allow the plant to operate more efficiently.

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1. Introduction and Background

Wastewater treatment plants (WWTP) are integral in our society. Without them, harmful waste would be released into the waterways and pose health risks to the public. To ensure proper operation, data is collected and analyzed by sensors and control systems. Certain types of software tools, such as Supervisory Control and Data Acquisition (SCADA), are used in the operations of WWTPs. Many WWTPs use inefficient devices that have surpassed their expected lifetimes. Inefficient WWTPs may improperly discharge pollutants, such as metals, oils, and grease, into waterways than contain high levels of nitrogen. This is a threat to the overall water quality and human health (EPA, 2018). Outdated control systems require higher energy usage, resulting in higher operating costs that can negatively impact a treatment plant (Lobo, 2017).

Many old SCADA systems face significant setbacks, such as higher operation costs and restricted software (R.F Wireless World 2012). Newer plants have been built using the Internet of things (IoT) technology, which is the connection of physical devices to the internet (Meola, 2016). IoT can connect all of the devices on the plant floor to a single cloud-based network.

Our project addressed the specific needs of the San Felipe Pueblo WWTP. Our sponsor, Souder, Miller and Associates (SMA), took control of plant operations in 2017 (SMA Operations LLC, 2018). Prior to the acquisition, the plant had been operated inadequately. With this project, we intend to assist SMA in the development of strategies that can be used to improve operations at the San Felipe WWTP

1.1 Wastewater Treatment Plants

Wastewater treatment plants remove bacteria and solid waste from water by converting wastewater into bilge water that can be released back into the environment. The treatment plants dispose of the trash and toxic waste, decompose organic matter, and restore the oxygen content of treated water. They complete this process through four sets of operations: preliminary, primary, secondary, and sludge treatments.

1.1.1 Stages of Treatment

Throughout the preliminary phase, the WWTP removes large items by using a set of screens to scrape up items such as tree limbs, garbage, and other waste materials (Bank, 2017). As shown in Figure 1, treatment plants have equalization basins and grit chambers, which regulate the rate of water inflow allowing for stones and glass to settle out. Basins hold sewage

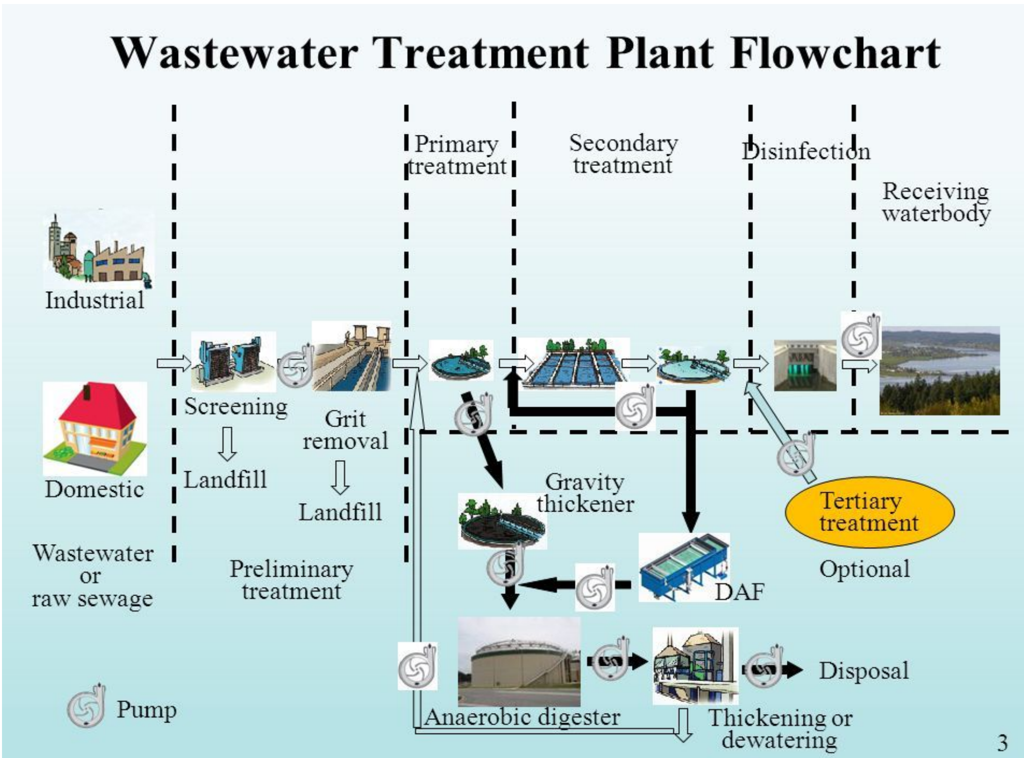


Figure 1. Diagram of a WWTP (Park, 2016)

until it is prepared to be treated and handles the overflow during heavy rain (Bank, 2017). If there is any residue grease or fat from the surface of the water, air blowers freeze the oily material for easier removal.

The next phase is the primary phase, which involves collecting the wastewater and placing it in large sedimentation tanks and basins. The smaller particles settle out of the water through gravity, while larger solid matter is collected through a mechanically driven scraper. Those particles are then directed to the containers connected to the sludge treatment equipment

(Bank, 2017). Most treatment plants remove the grease or fat from the surface of the water during the preliminary phase, where it can then be processed to make soap (Bank, 2017).

The secondary treatment process consists of oxygenating the wastewater in secondary basins, which adds helpful microorganisms to break up organic matter into sludge. Treatment plants have different methods to decompose sludge. Some treatment plants can breed a mass of microbes and pass the waste material over to a thin coating of bacteria, which will break down the waste (Bank, 2017). Another method to break down the refuse is to mix the bacterial biomass with the waste material creating sludge that can be recycled for soil.

The final phase is the sludge treatment phase, which consists of treating the remaining water and sludge. The small organic waste is separated from the larger lumps through gravity. The remaining primary sludge passes to a thickener, where it is centrifuged and fed to digesting tanks containing anaerobic bacteria (Bank, 2017). The tanks are used to produce methane which will then power the plant. The remaining wastewater is then treated to remove all the toxic chemicals including phosphorus and nitrogen. After treatment, the water is then returned to the water supply and the remaining solid sludge is cleaned to be used as fertilizer for soil (Bank, 2017).

All the discharge from the treatment plants must meet US Environmental Protection Agency protocol (Bank, 2017). The EPA uses the Industrial Wastewater Treatment Technology Database (IWTT), to investigate treatment technologies (EPA, 2018). The IWTT provides technology performance data, and peer-reviewed journals about treatment plants. The IWTT can identify specific technologies that can treat certain pollutants in a treatment plant (EPA, 2018). Treating these pollutants is good for the environment because the pollutants will not be flowing through waterways and spreading to other ecosystems.

1.2 Control Systems

A control system is a device or set of devices that regulates the behavior of another system to achieve a desired result (Rouse, n.d.). They can range from a basic system, such as a thermostat or heating unit, to extremely complex, such as the system used to keep nuclear power plants running.

In a WWTP, the control system acts as the brain to collect and disseminate data, process commands, and output control actions to operate the plant. WWTPs, along with many industrial processes, use a system called supervisory control and data acquisition (SCADA) as their control platform. These SCADA systems are composed of four major parts: field instrumentation, programmable logic controllers (PLCs), communications, and the SCADA host platform (Avrahami, n.d.) Each part of the system is vital to the operation of the plant. When one or more pieces fail to work correctly, overall operation of the plant will suffer or even stop.

The first piece in a SCADA system is the field instrumentation, which is further split into two distinct pieces: sensors and control devices (Avrahami, n.d.). Sensors are used throughout the WWTP to gather data such as rate of flow, turbidity of the water, or temperature during treatment. This data is aggregated from the sensors to the SCADA host platform where operators can use it to make decisions on how to continue operating the plant (Avrahami, n.d.). Control devices act the opposite way. The take an input data from the operator or PLC and carry out a task based on this data. Field instruments can also be a combination of a sensor and a control device, such as a pump that reports how much water is flowing through it.

The next piece is programmable logic controllers. PLCs are programmed by an operator to perform logic on the incoming and outgoing signals which they control (Gonzalez, 2015). Each field instrument is connected to one or more PLCs, which are in turn connected to the SCADA host platform so operators can readout data from sensors or manually control processes.

All the connected devices must communicate with each other. This can be done through wires or wirelessly, and over many number of different communication protocols determined by the types of devices and even the manufacturers (Avrahami, n.d.). Two different sets of communications must happen: communication between each field instrument and a PLC, and communication between the PLC and the SCADA host system.

Field instruments typically connect to a PLC using what is called a 4-20 milliamp (mA) control loop, seen below in Figure 2 (Paonessa, n.d.). To illustrate, we'll look at a sensor device, specifically a flow meter. In this example, water flows past a small turbine and spins it relative to the speed of the water. This spinning is detected by the flow meter as a certain amount of water flowing past. The flow meter then transmits this information to the PLC by adjusting the current flowing in the wires connecting the devices. The PLC detects this current, converts it to a readable value, and reports it to the SCADA host. To make this conversion accurately, the PLC must be calibrated to understand the sensor output. If calibrated incorrectly, the PLC will report the wrong value to the SCADA host.

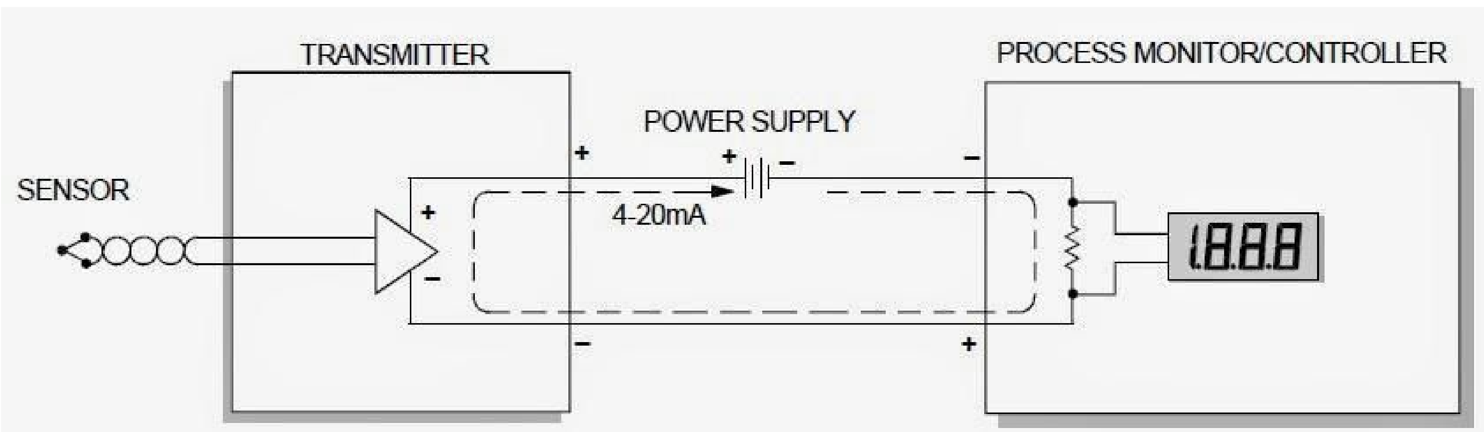


Figure 2: 4-20mA Current Loop (Ali, 2014)

The last part of the system is the SCADA host platform, which includes a SCADA engine, databases, and a human machine interface (HMI) (Avrahami, n.d.). The SCADA engine interfaces a computer with the PLC to log and refer to data stored in databases. The HMI also talks to the database to provide a nice user interface for the operators to view data from sensors and control different devices as seen in Figure 3.

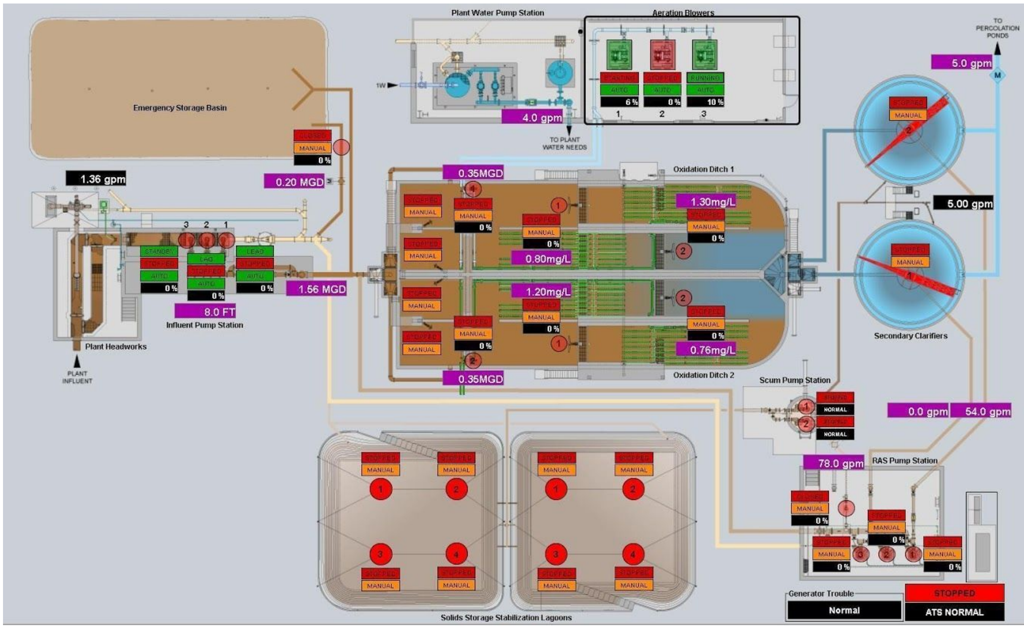


Figure 3: WWTP SCADA HMI (Wootton, 2013)

1.3 WWTP Inspections

Problems can arise if the control systems that operate the wastewater treatment plants are outdated and obsolete. These problems include municipal wastewater overflows, pollutants being improperly discharged, and storm water pollution. Whenever raw sewage overflow is inadequately controlled, it can end up in waterways and backup into city streets or the basements of homes. This overflow can be caused by system errors and human errors which can threaten water quality, human health, and the environment (EPA, 2018).

Before control systems at a WWTP can treat wastewater, there is pretreatment involved. The Environmental Protection Agency (EPA) implements the National Pretreatment Program to ensure that industrial and commercial facilities discharging to publicly-owned treatment works (POTWs) do not discharge untreated pollutants. These pollutants, which include metals, oils, and grease, can interfere with the operation of POTWs (EPA, 2018). If POTWs are interfered with, those pollutants are discharged into waterways.

For wastewater treatment plants, there is a program called the National Pollutant Discharge Elimination System (NPDES) that regulates the discharge of pollutants into the waters of the United States (EPA, 2018). This program helps protect the environment in the surrounding areas of WWTPs across the country, by conducting inspections for municipal wastewater overflows, pretreatment facilities, and stormwater pollution (EPA, 2018).

The EPA conducts inspections for wastewater overflows, by verifying that the person operating the plant, or the permittee, is preventing combined sewer overflows during dry weather. The permittee must also adhere to a schedule in the long-term control plan to eliminate overflows in sensitive areas (EPA, 2018). Human errors can occur at pretreatment facilities and The National Pretreatment Program exists to try and prevent human errors from occuring.

In addition to the National Pretreatment Program, there are inspections conducted on pretreatment facilities by the EPA. The inspections involve reviewing the approved program, compliance status, previous inspection reports, citizen complaints, and various industrial user operations. (EPA, 2018) Stormwater pollution also requires inspections to protect bodies of water from being polluted because of effluent being improperly discharged from WWTPs. These inspections include reviewing and observing best management practices and control measures, sampling stormwater discharge, and interviewing people involved with the facility operations (EPA, 2018) In terms of our project, if the San Felipe WWTP is not in compliance with both EPA and New Mexico standards, our group cannot complete the project.

At the state level, owners of wastewater treatment facilities are responsible for ensuring that liquid waste does not pose a public safety hazard. (New Mexico Environment Department, 2018) Since there are many forms of pollution that can occur due to outdated control systems, there are a variety of inspections involved. In New Mexico, inspections are dealt with at a state level, in addition to the federal government. The inspections are conducted to review and observe the current operations of those facilities and determine where improvements can be made. Once these improvements are made, WWTPs can increase their performance and have a positive effect on the surrounding community.

1.4 Internet of Things

The connection between the internet and physical devices is called the Internet of Things. The term “Internet of Things”, or IoT, was popularized in 1999 at MIT’s Auto-ID Center (Yang, 2014). IoT is the connection of all network capable “smart” objects to a single network, the internet (Miorandi, Sicari, De Pellegrini, Chlamtac, 2012).

The goal of IoT is to connect every smart object to the internet. This would allow information to be shared between the physical and the digital world (Yang, 2014). This would also allow machines to share information with each other and without human interaction. The communication between the machines would allow for improved speed, efficiency, and quality of data gathering and analysis (Hunzinger, 2016). The machine to machine communication (M2M) is key to how IoT functions. This communication between smart devices on a common network allows for information to be collected, processed, and analyzed without the need for human intervention.

IoT is used for three major tasks: data collection, data analysis, and system security (Vermesan & Friess, 2012). IoT systems collect, analyze, and share data through four major stages (Fuller, 2018). In the first stage, data is collected from a device in an analog form using sensors or monitors, then sent to the second stage in which it is converted from analog to digital (Fuller, 2018). In the third stage, IT systems then preprocess the data and send it to the fourth stage, where it is analyzed, processed, and stored in a data center or cloud system (Fuller, 2018).

While system security is not a specific function of IoT, it is necessary in order for IoT to function properly and be free of outside interference, such as hackers and viruses. The acquisition and analysis of information through interconnected devices would allow for more reliable and efficient data (Vermesan & Friess, 2012). Attacks on IoT have been a significant problem for SCADA systems and other industrial systems (Rambus, n.d.). There are several ways to help protect IoT against hackers and security breaches, including encryption and increased monitoring (Rambus, n.d).

1.4.1 Industrial IoT

While IoT is often used for consumer devices, it is also used in the development and operation of industrial processes, such as factories and infrastructure. Though there is currently no standard definition, the use of IoT in industrial processes, such as manufacturing, is referred to as Industrial Internet of Things (IIoT) (Rouse & Aberle, 2015). IIoT systems have the same connections and operations as consumer IoT devices, but operate on a larger, more critical scale, such as factories and electrical grids and therefore require more robust connections with longer service lives (Gold, 2018).

IIoT has applications in many industries, including healthcare, transportation, manufacturing, and oil production (Gilchrist, 2016). IIoT has applications in any industry in which data is collected in one device, and used in another.

Plants and factories have used network connected sensing devices to monitor equipment, machinery conditions, and product quality (Serpanos & Wolf, 2018). The use of IIoT has also allowed for the rise of smart factories, with plant automation and more efficient data collection (Breivold & Sandström, 2015). Swisslog created an IIoT system for warehouses, called SmartLIFT, which uses location sensors, RFID chips, and barcodes to help employees find products more easily (Gilchrist, 2016).

Oil production companies have used IIoT to increase safety for those working in the field by implementing monitoring systems to allow for more reliable maintenance predictions and to monitor changes in operating conditions on production machines (Shoja & Jalali, 2017). Oil rigs and drills have been outfitted with sensors that help engineers with real-time reservoir management (Gilchrist, 2016).

In healthcare, IIoT has been implemented for many purposes, but has largely been implemented for remote monitoring. This technology allows doctors and nurses to monitor patients without having to meet with the patient. At Guy’s and St. Thomas’s Nation Health Service Foundation Trust in the UK, doctors have created a system that allows patients to monitor their weight, heart rate, blood pressure, and oxygen levels at home with their smartphones. The data is then sent to nurses who analyze the data treat the patients accordingly (Gilchrist, 2016).

1.4.2 IoT in WWTPs

Given the data and communication based nature of WWTPs, IIoT has many applications in the wastewater industry. The SCADA systems at WWTPs operate in such a manner that different devices conduct different tasks, such as pipe burst detection, and water quality testing. Since SCADA relies heavily on data transfer between devices that collect data and devices that analyze data, IoT is the natural progression of SCADA (Hunzinger, 2016). IoT can streamline and automate the transfer of data between devices by connecting these devices to a network, which allows them to exchange data with each other.

The most promising use for IoT in the wastewater industry is in water monitoring and control (Turcu, Turcu, Gaitan, 2012). Many of the IoT devices currently used in the industry involve remote sensors which send data to the cloud for analysis (Chandrappa et al., 2017). These devices are inexpensive and relatively simple to install. One such device, the Waspmote, by Libelum, is an IoT monitoring system that can read water temperature, pH, turbidity, dissolved oxygen content, atmospheric conditions, and conductivity (Alba, 2017).

IoT has already been implemented into wastewater treatment. IoT was used in Hurghada, Egypt to administer and detect bursts in the city's water system (Afifi, Abdelkader, & Ghoneim, 2018). Prior to the adoption of IoT, Hurghada had problems with bursts and leakages going undetected. A system of sensor nodes was placed on the pipes and connected to a monitoring system to detect bursts. The use of IoT made detecting these bursts significantly easier and allowed for more efficient water distribution than manual detection.

IoT was also used in a project conducted by the Institute of Urban Environment at the Chinese Academy of Sciences. The project created an online water quality management system (OWQMS) that managed the quality of reused wastewater and surface water from a local bay (Wang et al., 2013). This water was used for landscaping and to maintain water levels in a local river. The OWQMS was able to effectively monitor the pollution levels of the reclaimed water so that only clean water would be used in the river.

As the demand for clean water increases, many communities and corporations have started to consider recycling wastewater (Li, Arnold, Kozel, Forster-Cox, 2005). Current wastewater treatment practices may meet discharge requirements, but are not safe enough for reuse (Wang et al., 2013). In 2014, engineers from IBM and Haifa used IoT to update the WWTP in Lleida, Spain and recycle wastewater (Zadorojniy, 2016). Prior to the IoT system, the settings and resources at the plant were adjusted seasonally based on the intuition of the operators. Under the IoT based system, the devices at the plant were constantly monitored by sensors, and setting recommendations were given every 2 hours (Zadorojniy, 2016). The plant was able to reduce electricity use by 13.5%; chemical use by 14%, and sludge production by 17% (Zadorojniy, 2016).

While IoT has been implemented in wastewater treatment, it has largely been used for water monitoring systems. IoT can potentially be used to conduct water tests, analyze data, detect and fix problems on the plant floor, and conduct many other plant operations. IoT has the potential to revolutionize the industry, saving corporations and local governments time, money, and resources.

2. Methodology

The goal of this project was to assist Souder, Miller and Associates in the development of strategies that can be used to improve operations at the San Felipe WWTP. This goal was achieved by completing two objectives. The objectives are:

1. Create a data collection system for operators of the treatment plant.
2. Create a strategic plan to guide future operations at the San Felipe WWTP.

In this chapter, we describe the methods we used to complete each objective and why we chose them. All of the objectives helped us determine how we could assist Souder, Miller and Associates to improve operations at the San Felipe WWTP.

2.1 Create a Data Collection System

At the San Felipe WWTP, operators record data directly from the SCADA host, without going on the plant floor. This can be problematic because the PLC that connects the physical devices to the SCADA host may not be calibrated correctly, causing the host to report incorrect information (di Ruggiero, personal communication). We created a form that requires plant operators to walk the plant floor to collect data from the readouts on the devices, the data from which can be compared to the data from the SCADA host to determine if there are discrepancies. The form will also enable the operators to report problems on the plant floor, such as rust or leaks.

2.1.1 Create a Survey123 Form

To allow operators to quickly and accurately collect data from devices around the plant, we developed a form using an app called Survey123 for ArcGIS. Survey123 is an app developed by Esri, a geographic information system company specialized in mapping software and spatial data analytics (Esri, 2018). Survey123 is a data collection system based on forms, or surveys, that provide a simple and intuitive user interface to gather information. The data gathered is captured and recorded in real time to a web interface where it can be viewed and manipulated (Survey123, 2018). The data can also automatically be populated onto a map to spatially reference where each question was answered.

First, we created QR codes for each device that operators needed to collect data from. A QR code is a type of 2D barcode that can hold many types of data. In our QR codes, we embedded a device name. We generated each QR code using online tools such as https://www.qr-code-generator.com/ or https://www.qrstuff.com. At the request of our liaison, each QR code contained the name of a device, and could be expanded to include information such as a link to the manual or the devices exact geographic location.

We used Survey123 Connect, the desktop app for creating Survey123 forms, to make the form for the San Felipe WWTP. To get started, we had a discussion with our liaison John di Ruggiero to outline the different components we needed to include in the form. From this we were able to create a rough draft of the form, shown below in Figure 4. In the draft shown, there are basic questions such as name of the operator and date/time of filling out the form followed by places to scan the QR code for a device and input the data from the device. To allow a comparison between the data shown on the SCADA host and the data displayed on the devices, the form is ideally used daily by the operators. After showing this draft to Mr. di Ruggiero, he recommended making changes based on his experience with Survey123 and how the operators

	A	B	C	D	E	F
1	type	name	label	hint	constraint	constraint_message
2	dateTime	ReportDateTime	Date and Time Observed			
3	select_one yes_no	BarScreenClean	Bar Screen Cleaned			
4	select_one yes_no	WalkThrough	Walk Through			
5	geopoint	TreatmentPlantLocatio	Treatment Plant Location			
6	begin group	GroupL100	L100 Devices			
7	barcode	QRCode	Train1 Flux			
8	image	DataImage	Data of Train1 Flux			
9	text	DataReadOut	L10_Train1Flux/Flux/Output			
10	barcode	QRCode2	Train Permeabillity			
11	image	DataImage2	Data of the Train Permeability			
12	text	DataReadOut2	L10_Train1Permeability/Permeability/Output			
13	barcode	QRCode3	Train1 TMP			
14	image	DataImage3	Output of Train1 TMP			
15	text	DataReadOut3	L10_Train1TMP/TMP/Output			
16	barcode	QRCode4	Lift Station			
17	image	DataImage4	Lift Station Level Output			
18	text	DataReadOut4	L100_LiftStationLevel/Level/Output			

Figure 4: Survey123 Form Questions

interact with technology. This led to another draft of the form that we then performed further testing on.

2.1.2 Testing and Data Collection

To ensure the survey form we created was user friendly we tested it with other WPI students at the project center. We printed some of the pictures of the devices Mr. di Ruggiero provided us along with their corresponding QR codes and placed them around a room (see Appendix A for pictures and Appendix B for QR codes). We then handed a phone with our survey loaded on it to each participant and asked them to go through it and collect data from each device. The participants went through the survey, scanning the QR codes and inputting data. We asked each participant to answer a few questions regarding how the user experience was (see Appendix C for questions). We then made changes based on these responses in an effort to improve the usability of our survey.

We planned to conduct further testing of the survey at the San Felipe WWTP. Using the survey at the plant would allow us to test the user interface along with how well the data input system worked. However, while we were in New Mexico the San Felipe Pueblo was closed to the public and we were unable to get onto the plant to test. We asked Mr. di Ruggiero to test the survey and use it to collect a preliminary data set from the devices. Unfortunately, Mr. di Ruggiero was unable to test our Survey123 form and collect a data from each device in the San Felipe WWTP. We will discuss this later in the Results and Conclusions sections of our report.

2.1.3 Data Analysis

With our Survey123 form data from the devices can be easily collected every day. The SCADA system automatically pulls data each day into an Excel spreadsheet. In our analysis, we planned to compare these two data sets, looking for discrepancies. We planned to compare the data day to day as well as look at the trends of each data set, comparing to ensure they were consistent with each other. Discrepancies between the two data sets would indicate a problem, for example, that a communication or conversion error is occurring between the device and the SCADA system.

After comparing for discrepancies, we planned to verify that the data was within the range of normalcy for each device. The range of normalcy is where the values reported from each device are not outside the limits of normal functionality (di Ruggiero, personal communication). The data from the SCADA system and Survey123 would be compared to a list of alarm conditions given to us by Mr. di Ruggiero. Both data sets should be within these ranges. The data reported by both the devices and the SCADA system could be within the range of normalcy, however, if both readings are still different, then the data is being reported or interpreted incorrectly. We were unable to complete this because we did not receive the data from the plant. We will discuss this later in the Results and Conclusions sections of our report.

2.2 Create a strategic plan for the operators at the San Felipe WWTP

In order for SMA to manage all the devices at the treatment plant, we developed a strategic plan. In this plan, we identified and suggested strategies that can be used at the San Felipe WWTP to improve operations.

2.2.1 Informal Interviews with Mr. di Ruggiero

Throughout the term we conducted many informal interviews with our liaison, John di Ruggiero. We discussed the current state of the plant, including how maintenance is typically performed, what emergency repair parts they have on hand, what training operators at the plant receive, and the standard operating procedures at the plant. This information helped us determine which areas of operations needed improvement.

2.2.2 Informal Interviews at WWTPs

In order to create a strategic plan for San Felipe, we needed to determine how other plants updated their facilities. To do this, we interviewed plant supervisors from the Taos Valley and Santa Fe WWTPs. We spoke to Jean Salazar and Efron Morales, the plant supervisors at Taos and Santa Fe, respectively. During these interviews, we asked how the plant operators conduct and upgrade operations and maintenance (see Appendix D for questions). These interviews focused largely on operator training, developing a maintenance schedule, and fixing or replacing devices in the plant.

We mainly interviewed the plant supervisors, as their positions and experience gave them a better understanding of plant operations than standard operators or engineers. Plant supervisors oversee the entire plant operations and have more experience and expertise than standard operators, who conduct daily operations. Operators also work directly on the plant floor and have hands on experience that the engineers do not have. The engineers at SMA design WWTPs, but they do not work on the plant floor with the operators.

2.2.3 Strategic plans for WWTPs

To get a better understanding about what treatment plants need in order to run efficiently, we analyzed the strategic plans of other treatment plants. We consulted treatment plants in Jackson, Mississippi; Shelby, North Carolina; and Newberg, Oregon. We examined the plans for each of the treatment plants to see if they can be applied to the San Felipe WWTP. In the procedures we specifically looked for their maintenance management, list of replacement parts, inventory control, and if they have a section on troubleshooting tips.

2.2.4 Contacted Manufacturers of WWTP Devices

In order to create an inventory of the devices currently at the plant, we contacted manufacturers of WWTP devices. The purpose of this list is to see what devices the San Felipe WWTP is currently operating with. We were given a partial list of the devices located at San Felipe. This list contained a maintenance schedule and manufacturers of the devices at the plant. The list did not, however, contain the model numbers of the devices. In order to determine which models were used at San Felipe, we consulted the websites of manufacturers. For websites that did not contain the necessary information, we sent information requests by email to all of the manufacturers. If we didn't hear back within two or three business days, we called the manufacturer. In these requests, we asked which device was sold to the plant (or was most likely sold to the plant), the expected lifetime of each device, the suggested retail price, and any other general information about the device. For any device no longer in production, we found a replacement device.

We also received a set of photos from Mr. di Ruggiero that contained the manufacturer and model number for many of the devices at the plant. We sent information requests to the manufacturers to determine the retail price and lifetime for each device. (See Appendix A for a table of the devices from both the list and the photos.)

2.2.5 Determine the Applications of IoT at San Felipe

Determining the application of IoT at the San Felipe WWTP required that we contact people who had used IoT in the wastewater industry. We contacted Alan Rogers, an engineer at SKM Engineering, a Utah based partner of SMA that designed the San Felipe WWTP. We asked Alan Rogers how SKM had implemented IoT for data collection, and how that data allowed operators to run the plant more efficiently (see Appendix E for questions).

We also contacted manufacturers of IoT devices, specifically Opto22 and Temboo, both of which provide IoT solutions to SCADA systems. We interviewed representatives from both companies over the phone (see Appendix F for questions). The interviews focused largely on how the products could be implemented into the current operations, how they operate and use IoT, the retail price, lifetime, and durability of the products. These questions allowed us to determine the costs and benefits of implementing IoT at the San Felipe plant.

3. Results

In this chapter, we describe the results of the methods described in the previous chapter, and how those results were analyzed. In order to assist SMA in the operation of the San Felipe WWTP, we created a data collection system and strategic plan for the plant.

3.1 Create a data collection system

We created a data collection system using Survey123 for the operators at the San Felipe WWTP. The system is a form that allows operators to record the readings from the devices on the plant floor, as well as to comment on the general state of the plant. The form's user-interface makes it easy for plant operators to collect data. Once a form has been submitted, the data is stored for analysis and record keeping.

3.1.1 Create a Survey123 Form

For each device in the plant, we created a QR code containing the name of the device. An example of a QR code we created can be seen in Figure 5. A full list of all the QR codes we created can be found in Appendix B.

Figure 5: QR code

Using Survey123 Connect we were able to create a user-friendly form to collect data from devices at the plant. The form consists of a section for general information such as name and date, and a data collection section. In the data collection section, devices are grouped by type. For each device, there is a place to scan the QR code, input the data from the device (either by typing, taking a picture, or both), and a section for other comments (users can either type, take pictures, or record audio). The beginning of the form can be seen in Figure 6 and an example of one of the device input sections can be seen in Figure 7.

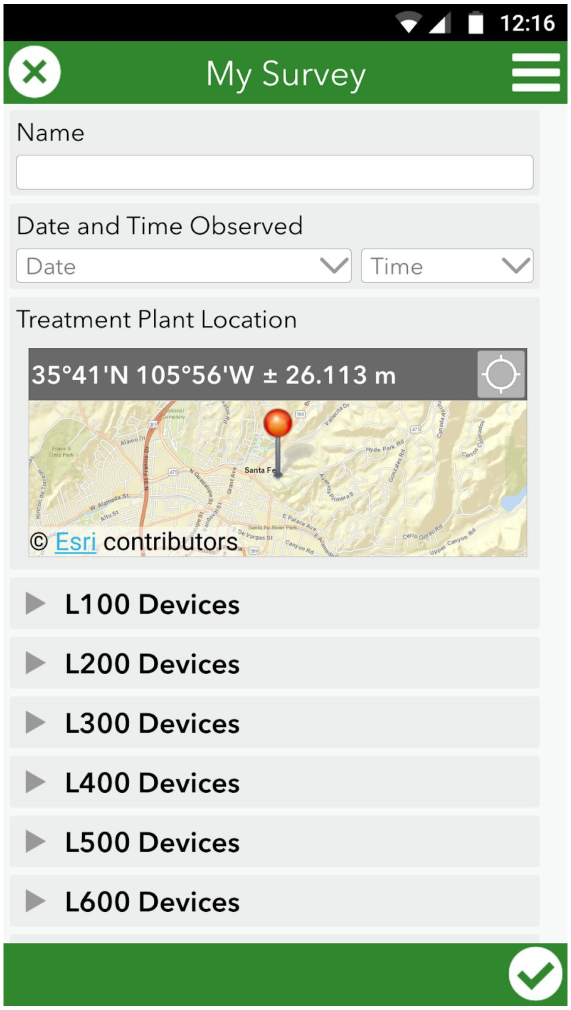


Figure 6: Survey123 form

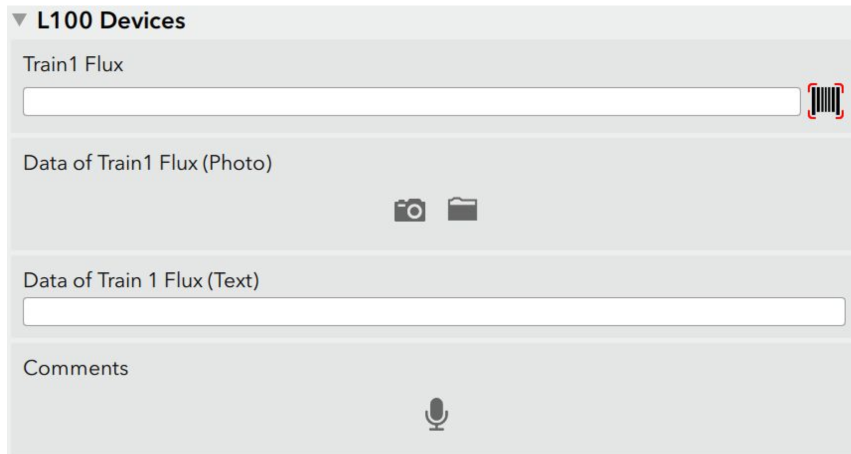


Figure 7: Device input section

3.1.2 Testing and Data Collection

A total of 11 students participated in the test of our Survey123 form, which we conducted in a common room of the Ft. Marcy Hotel and Suites on October 1st. During testing, each participant was asked to answer some questions regarding the usability and functionality of our survey (see Appendix C for questions). These responses provided us with information on how to change our survey to be more user friendly.

Our survey draft received an average user friendliness rating of 2.8 on a scale from one to five. We identified that 5 out of the 11 participants indicated that the naming conventions for the devices and fields in the survey were confusing. We also received feedback from 4 participants recommending we clearly identify each device in the survey. A full summary of responses can be found in Appendix G. Using this feedback, we made changes to the survey to ensure user-friendliness. Specifically, we simplified the names and properly labeled the devices and added a geospatial location to the form.

While we were unable to go to the San Felipe WWTP, Mr. di Ruggiero went and was able to provide us with images of some devices at the treatment plant (see Appendix A). He was unable to test the Survey123 form and collect data from the devices or the SCADA system. As a result of this we did not have the data from the devices and could not carry out our planned comparison of device and SCADA data to investigate the functioning of the SCADA system.

3.1.3 Data Analysis

To perform a comparison we needed two sets of data, the data directly from the devices collected using the Survey123 form and the data aggregated by the SCADA system. We were not able to get either of these sets of data, however the methods we described earlier can be carried out by SMA or another party when this data becomes available. The results of this comparison are important to ensure all parts of the system are calibrated correctly and accurately reporting and recording data.

3.2 Strategic Plan

We created a draft strategic plan for the operators at the San Felipe WWTP. The plan will assist the plant operators in determining the future actions of the plant. In the plan, we describe changes to the operations and include ideas for future investments. These next sections discuss how we determined what should be in the strategic plan.

3.2.1 Informal Interviews with Mr. di Ruggiero

From the discussions with our liaison, we learned about the current state of the San Felipe WWTP. Mr. di Ruggiero told us that a majority of the maintenance conducted at San Felipe is reactive instead of proactive. Reactive maintenance focuses on restoring devices to their normal operation after they have broken down, whereas proactive maintenance focuses on anticipating and managing machine failures before they happen (Omega, 2018). Mr. di Ruggiero wants the operators to proactively maintain the plant instead of reacting to problems that occur. This will save the San Felipe Pueblo money in the long run because they will no longer need to replace broken devices as often (di Ruggiero, personal communication). In Figure 8 below, the graph

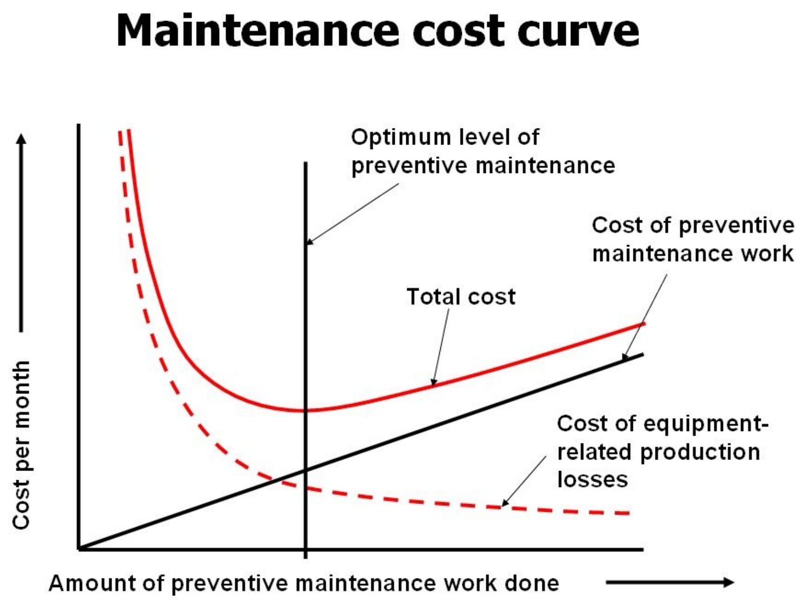


Figure 8: Maintenance Cost Curve (Veleda, 2018)

shows how engaging in preventive maintenance, which is a strategy of proactive maintenance, at an optimum level will reduce the total cost and the cost of equipment-related production losses (Veleda, 2018). However, if too much preventive maintenance is done, then the total cost will start to increase again. We also learned that some of the devices currently on the plant have started to malfunction. In particular, the PLC has passed its service life and many of its components have been corroded (di Ruggiero, personal communication). The PLC must be replaced in the near future.

We asked Mr. Ruggiero what emergency replacement parts were at the plant. He informed us that few devices had replacement parts. For the devices that did have replacement parts, the parts were limited and consisted of extra parts from when the plant was built (di

Ruggiero, personal communication). Having replacement parts would eliminate the time that operators spend locating, purchasing, and shipping replacement parts (di Ruggiero, personal communication).

3.2.2 Informal Interviews at WWTPs

Throughout the interview process, we found that several common themes emerged regarding training and maintenance. At both the Taos Valley and Santa Fe WWTPs, the supervisors told us that a successful plant must perform proactive maintenance, and operators must be trained to fix almost any problem that can occur at the plant.

The supervisors at both plants told us that maintenance is crucial to keeping devices functioning properly, and that maintenance must be performed in a preventative manner, so that devices can perform as efficiently as possible. Both supervisors said that operators maintained each device according to their operations manuals. The supervisor for the Santa Fe plant, Efron Morales, also said that operators inspect each device every 2 hours to ensure that the plant functions properly.

We also asked the supervisors how the plant went about replacing and/or fixing devices. The supervisors at both plants said that they rarely had to replace devices; devices could typically be fixed, or parts could be replaced, rather than the entire device. However, the supervisor at Santa Fe said that devices that cannot be easily fixed must be replaced (Morales, personal communication). According to Gene Salazar, the supervisor at the Taos plant, when SMA took over operations at the Taos plant, the operators went through each device, cleaned everything and fixed or replaced all broken parts (Salazar, personal communication). Both plants also had replacement parts for many of the devices at the plant. The Taos plant had either 2 or 3 replacements for each device that commonly broke or malfunctioned. The Santa Fe plant had a replacement part for each pump, motor, and any small part or component that could be replaced at a lower price than replacing the entire device (Morales, personal communication).

Training was another large area of discussion at the plants. The supervisors at both plants said that operators must be highly trained in plant operations, and must be able to troubleshoot almost any problem that arises at the plant. In the rare event that operators at the Taos Valley WWTP cannot fix a problem, they have a technician on-call at all times (Salazar, personal communication). The supervisor at the Santa Fe plant told us that, depending on his or her level, each operator should be able to fix most issues that could occur at a WWTP. An operator's level is his or her certification, with class 1 being entry-level and class 4 being the most advanced (New Mexico Wastewater Systems, 2007). According to Mr. Morales, all Class 3 and 4 operators must be able to fix nearly every problem that could occur, and must know how the entire plant operates, and how it should operate to determine what changes need to be made at the plant. Class 1 and 2 operators should receive this training as part of their basic training, so they can fix issues without having to receive help from the class 3 and 4 operators (Morales, personal communication).

3.2.3 Strategic Plans for WWTPs

We reviewed the strategic plans for other treatment plants and looked at the sections on operation and maintenance. We found that the treatment plants in Jackson, Mississippi all use a software program, known as eRPortal, a computerized maintenance management system (CMMS), to assist in maintenance management (Harrington et al., 2014). eRPortal demonstrates a sophisticated maintenance management that simplifies organizing assets (eRPortal, n.d.). The treatment plant in Shelby, North Carolina uses a different maintenance management program, known as Fiix (Turner, 2002). Fiix works similarly to eRPortal, but Fiix notifies operators when repairs should be made on devices (Fiix, n.d). All the repairs are documented in a work order form. A work order is an authorization of maintenance, or repair work to be completed (Emaint, n.d.). The strategic plan for the Newberg, OR plant includes a section on how the plant's operations could be affected by future events, such as changes to regulations (Brown and Caldwell, 2007). We also discovered that the treatment plants in Jackson have a section detailing troubleshooting tips for certain devices.

3.2.4 Contacted Manufacturers of WWTP Devices

From our liaison, we were given an operation and maintenance schedule which included a list of the types of devices and their manufacturers. We were also given pictures of some of the devices at the plant, from which we were able to determine model and manufacturer. From this, we were able to determine that many of the device models in the San Felipe WWTP have been discontinued. The list we compiled from these sources can be seen in Appendix A.

Our group was able to find all of the necessary information for the devices manufactured by ABB, Sigma Aldrich, Westech, Enviroquip, MSA, Neuros, Wedeco, and BDP. We were unable to obtain information regarding devices manufactured by Grundfos, KSB, LMI Milton Roy, Fluid Dynamics, and Gorman-Rupp because we did not have sufficient information regarding the specifications of the device from the plant. Our group emailed our liaison to request this information, but he was unable to find this information.

3.2.5 Determine the Applications of IoT at San Felipe

In order to determine the applications of IoT in WWTPs, we contacted Alan Rogers at SKM. Mr. Rogers told us that SKM predominantly uses IoT for data collection and analysis through the PLC and SCADA. He said that the use IoT has allowed not only the operators but also the engineers at SKM to collect more data. When engineers and operators have more data, they can make more informed decisions regarding plant operations and upgrades. Mr. Rogers said that more data allows a plant to run more efficiently, saving money on power, chemicals, and repairs. For San Felipe, Mr. Rogers recommended that the plant upgrade their hardware to newer, digital equipment.

We contacted IoT solutions companies, Opto22 and Temboo, to determine how IoT could be used in the San Felipe WWTP. Both companies provide IoT solutions for SCADA that include data visualization and alerts. We discovered Opto22 through our liaison, who recommended that we contact a sales representative to ask questions about the product. We discovered Temboo while researching IoT based PLCs.

We contacted Opto22 over the phone to see how their products could be used at the plant. We spoke to Kyle Orman, an engineer at Opto22, who said that the Groov EPIC would be the most useful product for the plant. Groov EPIC is a web-browser based controller that connects to devices at the "edge" of the network, such sensors and meters, through Ignition Edge SCADA (Orman, personal communication). Edge computing allows for data to be processed locally, at the "edge" of the network, as opposed to a centralized location (What is Edge Computing?, 2018). Groov EPIC uses edge computing to perform the same functions as a PLC. This allows data to be processed and utilized more quickly, as the data no longer needs to be sent to a centralized unit to be processed. As data is processed locally, devices that operate using edge computing will continue to operate, even in the event of a system failure (Gyarmathy, 2018). This means that if an issue were to arise in the SCADA, the system would be able to operate because the data is processed at the "edge", and not in the SCADA. Groov EPIC also provides users with data visualization and alerts. Compared to other IIoT systems, Groov EPIC is easy to install and requires minimal hardware. For a plant with 60 points of input or output, Groov EPIC typically costs about $3700, which includes the controller, power supply, chassis, and any other hardware necessary. The product is intended to last 10-15 years in an industrial environment, but there are Opto22 controllers that have lasted over 30 years.

We also contacted Temboo and spoke with Matt Plaks, a sales representative for the company. Mr. Plaks told us that the Data Visualization App for SCADA would be the best product for the plant. The Data Visualization App for SCADA is a browser based software that connects directly to the existing SCADA system. The app allows for data visualization and sensor alerts through web browsers. It can connect to any PLC that can connect to the internet, however, the Siemens S7 is recommended (Plaks, personal communication). The app includes an easy-to-use interface, customizable SMS or email alerts, and programmable data visualization. The app is a subscription based service that costs $12,000 per year. It is currently used in industrial applications, including for building management by the city of New York (Plaks, personal communication).

4. Deliverables, Recommendations and Conclusion

In this chapter we describe our suggestions and recommendations for the San Felipe WWTP. As a deliverable, we compile our research and findings into a strategic plan. This plan briefly outlines the current state of the plant including operational procedures and an inventory of devices. From there we go into our recommendations for ways to improve operation.

4.1 Strategic Plan

Purpose

The purpose of this document is to develop a plan to optimize efficiency at the San Felipe Wastewater Treatment Plant. Plant operations could be greatly enhanced with a rigorous operation and maintenance plan, and by upgrading the Programmable Logic Controller (PLC) with the Internet of Things (IoT). The strategies in this plan will allow the plant to gather more data, operate more efficiently, and save money.

Current State of the Plant

The San Felipe plant is currently operating with 58 different devices. Most of the devices are past their lifetime and need to be either replaced or fixed. Souder, Miller and Associates took over the plant in February, 2017 and were not given proper documentation of how the plant was previously run or how the devices were performing (di Ruggiero, personal communication). As a result of this, little data regarding plant operations was presented to Souder, Miller and Associates. Once they took over the plant, they tried to fix problems that occurred, without the knowledge of how problems were fixed in the past.

When malfunctions occur, the San Felipe WWTP does not have replacement parts for each device (di Ruggiero, personal communication). If the operators are not able to fix the problem and do not have replacement parts on standby, then the plant will be operating with a broken device, which can affect its overall functionality. The PLC is also in need of an upgrade or replacement. The PLC that the San Felipe WWTP is operating with is past its lifetime, the motherboard is very brittle and starting to fall apart, and the plastic on the outside of the PLC is starting to erode as a result of the environmental conditions in the WWTP (di Ruggiero, personal communication).

The San Felipe WWTP is not operating at an optimal level of safety. Below, in Figure 9, is an example of a gas meter alerting the operators of poor air quality. We were also informed of a dead battery caused an alarm in a lift station to go unnoticed for hours (di Ruggiero, personal communication). Not only is the plant not running as efficiently as it should be, but there is a concern about safety.

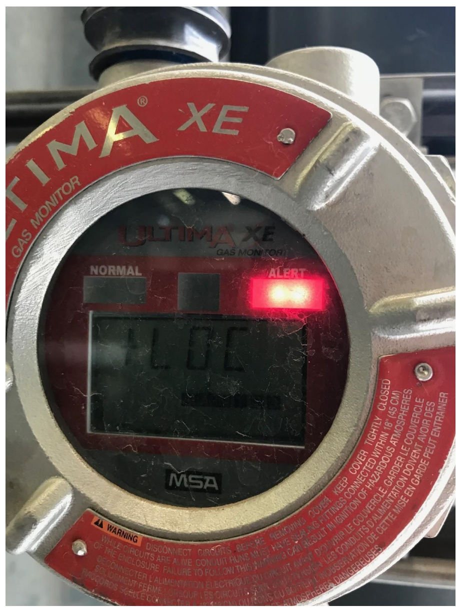


Figure 9: Alert on Gas Meter (Photo taken by Mr. di Ruggiero)

Equipment Inventory

Table 1, shown below, is an inventory of the devices at the San Felipe WWTP. This inventory will help the plant with asset management and replacing the devices currently at the plant.

Table 1. Inventory of Devices at San Felipe

Type	Make	Model	Production	Alternative	Price	Distributor
Belt Filter Press	BDP	0.9 M DDP	In Production	N/A	$255,000	Goble Sampson and Associates 480-696-3667
Blower	Neuros	NX100	Discontinued	NX100-C	$106,750	Water Technology Group 800-875-2515
Cake Pump	BDP	BT 5-12	In Production	N/A	$25,000	Goble Sampson and Associates 480-696-3667
Flowmeter	ABB	MagMaster	Discontinued	CoriolisMaster	$3000	Thomas & Betts 901-252-5000
Gas Monitor	MSA	Ultima	In Production	N/A	N/A Need specifications	Demand Safety 505-814-7711
Influent and Effluent Sampler	Sigma Aldrich	N/A	N/A	SPME Portable Field Sampler	$373	Manufacturer- Sigma Aldrich 800-325-3010
Lift Pump Station	KSB	N/A	N/A	Ama-Porter CK Pumpstation	N/A Need serial number	Alpha Southwest 505-877-0287
Membrane Basin	Enviroquip/ Kubota	N/A	N/A	Ovivo MBR	$9/gal	Manufacturer- Ovivo 855-466-8486
Microprocessor Dosing Pump	LMI Milton Roy	A-series	Discontinued	B-series	N/A Need specifications	Pumps and Controls 817-472-7337
Permeate Pump	Gorman-Rupp	T-series	In Production	N/A	N/A Need serial number	James Cooke and Hobson 505-344-7100

Polymer Blending System	Fluid Dynamics	N/A	N/A	Dynajet Dry Polymer Feed System	N/A Need specifications	Municipal Treatment Equipmen 303-231-9175t
Sludge Pump	BDP	BN 15-6LT	In Production	N/A	$20,000	Goble Sampson and Associates 480-696-3667
Spiral Screen	WesTech	Cleanflo	In Production	N/A	N/A	Manufacturer- Westech 801-265-1000
Turbidity Meter	N/A	N/A	N/A	N/A	N/A	N/A
Utility Water Pump	Grundfos	N/A	N/A	N/A	N/A Need serial number	Alpha Southwest 505-877-0287
UV Unit	Wedeco	LBX-200	In Production	N/A	$70,000	Manufacturer- Xylem 914-323-5700

Operations and Maintenance

There are two basic parts to running any WTTP: operation and maintenance. A WWTP needs to operate continuously, because wastewater is constantly flowing into the plant and must all be treated. Operators work at plants to ensure continuing operation, making adjustments necessary based on differing conditions such as changes in the influent, environmental factors, or issues with the equipment. Maintenance needs to be performed regularly to keep equipment working efficaciously. When issues do arise, it is the job of the operators to overcome them and keep the plant running. Wastewater does not stop flowing to the plant, it is the job of the operators to ensure all of it is treated properly before discharge.

Fix or Replace Problematic Devices

Having operated for the last 12 years without proper maintenance, all of the devices currently at the plant need to be either fixed or replaced. Many of the devices may only require minor fixes, such as removing fats, oils and greases; others may require more serious replacements. Any device which cannot be fixed easily, must be replaced (Morales, personal communication). As mentioned earlier, the PLC is past its service life, and must be replaced.

The plant should also purchase replacement parts for any device or device component that commonly breaks, or is critical to plant operations. The Taos plant has 2-3 replacement parts for any device that commonly breaks, or is critical to plant functions (Salazar, personal communication). The Santa Fe plant has replacement parts for any component that can be replaced at a lower cost than replacing the entire device (Morales, personal communication). The San Felipe plant should purchase replacement parts for any device or device component that commonly breaks or is critical to plant operations. Whenever a component of a device can be replaced at a lower cost than replacing an entire device, the plant should purchase the components instead of the entire device. Purchasing replacement parts will save the plant time on locating, purchasing, and shipping replacement parts, which will, in the long run, save the plant money and resources.

Develop a Proactive Maintenance Schedule

In order for the San Felipe WWTP to efficiently create a maintenance schedule they should use a CMMS. A CMMS is an operational tool used for managing assets of an organization. The information will be used to assist the maintenance workers to do their jobs more effectively, by determining which devices require maintenance. The maintenance schedule is determined by an asset and equipment hierarchy. An asset hierarchy ranks the equipment in order of importance to the functioning of the plant. This allows the operators to identify which devices maintenance can performed on. Integrating a CMMS system will aid in scheduling maintenance tasks that will decrease the number of breakdowns (Walker, 2017). The management team at the San Felipe WWTP must determine what the cost of repairs are versus the cost of the CMMS software and the time to manage it as well. This will help the management personnel decide if using a CMMS will be cost beneficial.

There are many different CMMS software packages available. When we were researching the various software packages we were specifically looking for ones that were used in a WWTP. We also looked for software packages that were used for small to medium sized organizations and we looked at the features the systems provide. We recommend using Fiix, or eRPortal because they are used in WWTPs and features would be beneficial for the San Felipe WWTP. Fiix is currently being used in a WWTP in Shelby, NC, while eRPortal is being used at the three WWTPs in Jackson, MI.

Fiix offers a customizable and interactive dashboard which can sort through all data for the user. Information regarding overdue work orders, low stock items, or work requests will appear first on the dashboard (Fiix, n.d). The software also allows the user to easily import their pre-existing assets and maintenance data from Excel (Fiix, n.d.). If the user does not have any pre-existing data, then all the information must be manual entered. The user can create work orders, view who is working on it and get a notification when the work order has been completed. As shown in Figure 10, the work orders can be labeled depending on what kind of work the user is doing. Fiix can manage the inventory by automatically tracking stock levels so

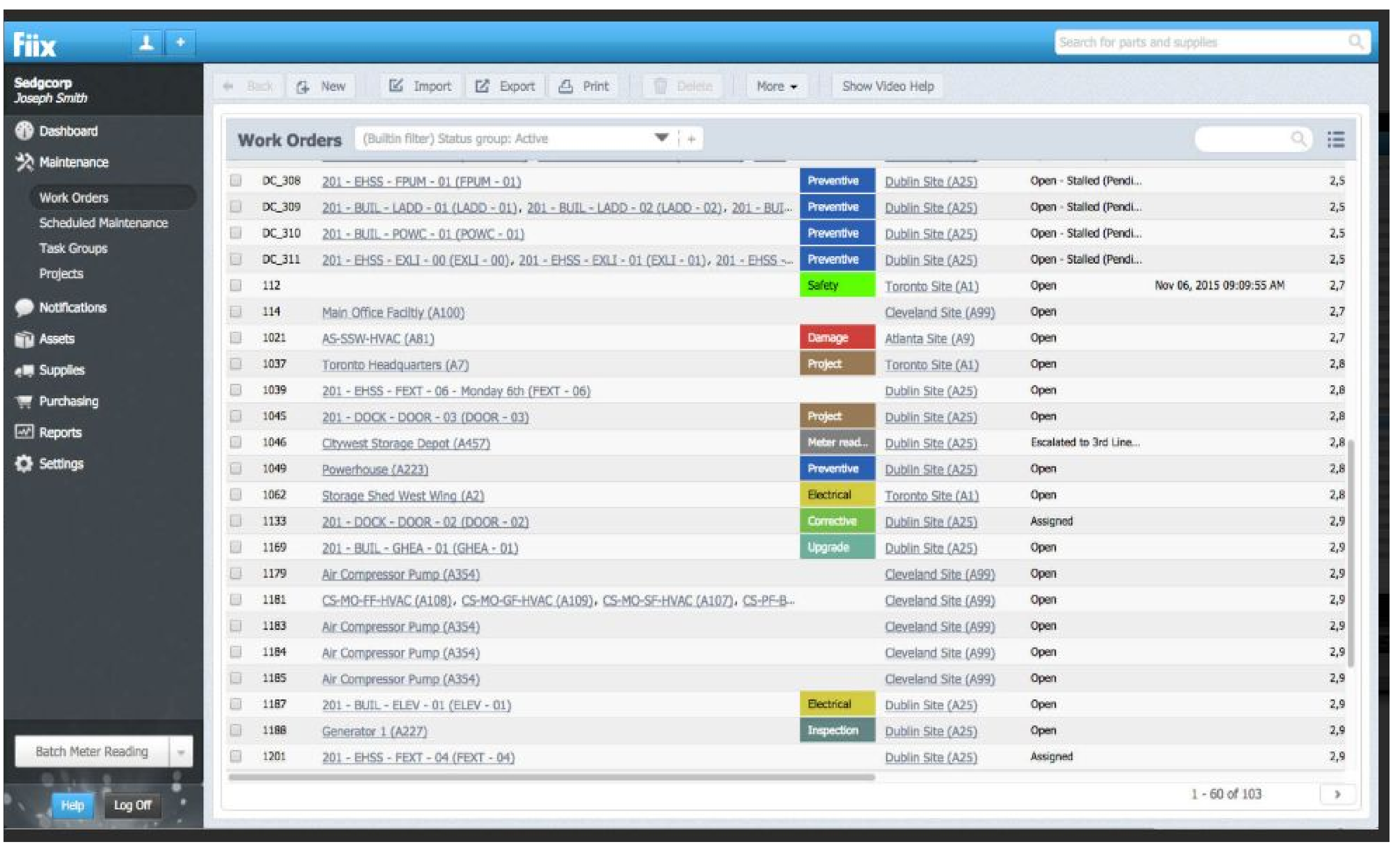
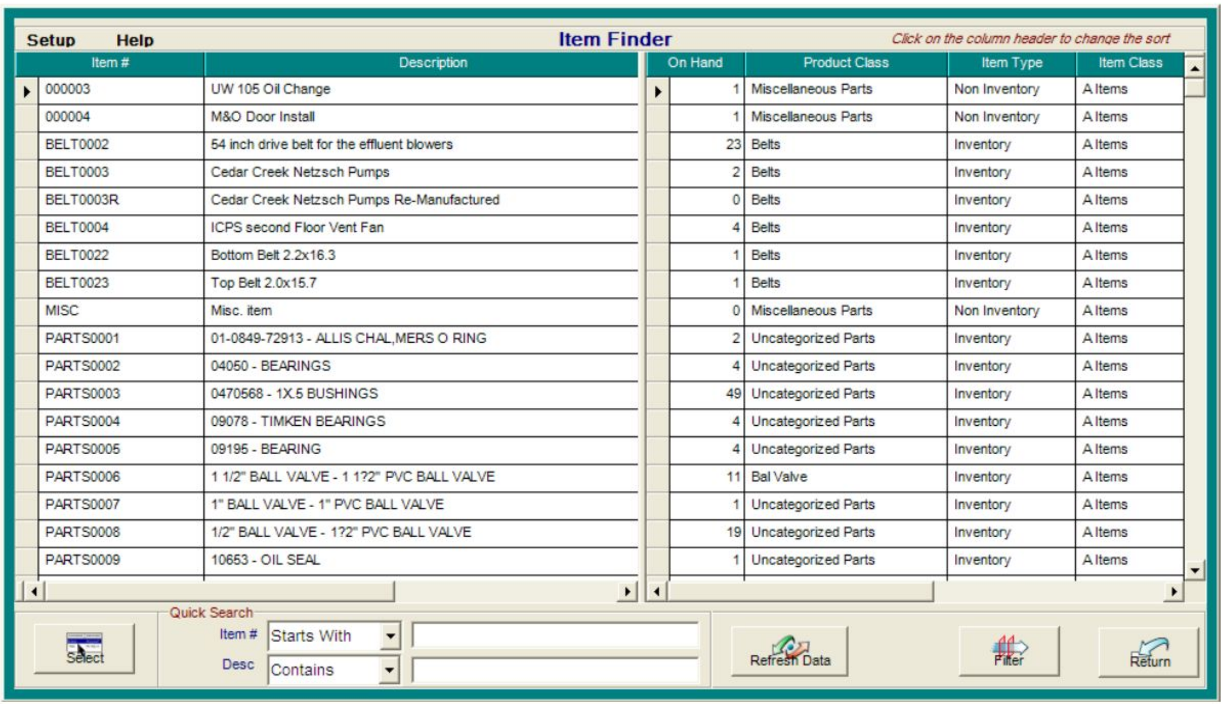


Figure 10: Fiix Work Order Interface (Fiix, n.d.)

operators can check online to see if a part is available instead of physically checking. The system has a minimal inventory level for parts, so if a part falls below the minimum level then the user will get notified to reorder the product. This reduces the chance of a stock shortage by taking the guesswork out of reordering. In terms of cost there are two different payment plans, the basic and the professional plan. The basic plan costs $35 a month and offers the basic maintenance management software (Fiix, n.d.). The basic plan is normally used for small businesses, and does not contain many advanced features. The professional plan is the most popular plan and contains the complete maintenance management software. The professional plan costs $55 a month and contains most of the advanced features (Fiix, n.d.). Between the two plans we recommend the basic plan because it costs the least and has all the basic features for the San Felipe WWTP.

eRPortal is another CMMS software that is designed to increase the effectiveness of the operations and maintenance at a WWTP (eRPortal, n.d.). The system tracks and automates all maintenance activities. eRPortal is arranged to be flexible in terms of how the user operates, track their items, and their workload (eRPortal, n.d.). This program also has the capabilities to connect with a SCADA to allow condition work orders based on the sensors being monitored (eRPortal, n.d.). eRPortal has the ability to monitor spare parts, as shown in Figure 11. The figure shows how eRPortal manages spare parts at a treatment plant in Jackson, MI. This table organizes the items based on the type of item, whether it is a miscellaneous part, or a part for one of the devices. This table also monitors the quantity of the items that are on hand. The lowest price would be $1500 a year and the highest would be $8000 a year (eRPortal n.d.). The price of eRPortal varies based on the amount of devices at the treatment plant, and any specific features that would be added. The San Felipe WWTP would have to schedule a demo with a representative from eRPortal and then get a quote.

Before purchasing either product we recommend that the operators schedule a demonstration of each software package so that they have an understanding of how the program works. We recommend that there should be a CMMS team consisting of people familiar with maintenance operations. This team's feedback is important because they understand what is best



Item #	Description	On Hand	Product Class	Item Type	Item Class
000003	UW 105 Oil Change	1	Miscellaneous Parts	Non Inventory	A Items
000004	M&O Door Install	1	Miscellaneous Parts	Non Inventory	A Items
BELT0002	54 inch drive belt for the effluent blowers	23	Belts	Inventory	A Items
BELT0003	Cedar Creek Netzsch Pumps	2	Belts	Inventory	A Items
BELT0003R	Cedar Creek Netzsch Pumps Re-Manufactured	0	Belts	Inventory	A Items
BELT0004	ICPS second Floor Vent Fan	4	Belts	Inventory	A Items
BELT0022	Bottom Belt 2.2x16.3	1	Belts	Inventory	A Items
BELT0023	Top Belt 2.0x15.7	1	Belts	Inventory	A Items
MISC	Misc. item	0	Miscellaneous Parts	Non Inventory	A Items
PARTS0001	01-0849-72913 - ALLIS CHAL,MERS O RING	2	Uncategorized Parts	Inventory	A Items
PARTS0002	04050 - BEARINGS	4	Uncategorized Parts	Inventory	A Items
PARTS0003	0470568 - 1X.5 BUSHINGS	49	Uncategorized Parts	Inventory	A Items
PARTS0004	09078 - TIMKEN BEARINGS	4	Uncategorized Parts	Inventory	A Items
PARTS0005	09195 - BEARING	4	Uncategorized Parts	Inventory	A Items
PARTS0006	1 1/2" BALL VALVE - 1 1?2" PVC BALL VALVE	11	Bal Valve	Inventory	A Items
PARTS0007	1" BALL VALVE - 1" PVC BALL VALVE	1	Uncategorized Parts	Inventory	A Items
PARTS0008	1/2" BALL VALVE - 1?2" PVC BALL VALVE	19	Uncategorized Parts	Inventory	A Items
PARTS0009	10653 - OIL SEAL	1	Uncategorized Parts	Inventory	A Items

Figure 11: eRPortal Spare Parts Table (Harrington et. al., 2014)

to improve operations. During the demo the operators should make sure that the features stated previously, will meet their needs.

When it comes to maintaining a WWTP, operators can either practice proactive maintenance or reactive maintenance. Reactive maintenance focuses on restoring devices to their normal operation after they have broken down, whereas proactive maintenance focuses on anticipating and managing machine failures before they happen (Omega, 2018). We recommend that the operators proactively maintain the plant based on manufacturers' recommendations instead of reacting to problems when they occur.

When it comes to reactive maintenance, a technician is usually called in to fix broken equipment. The costs may be low until machine failure, but there is a greater expense for unexpected downtime (Omega, 2018). If operators have the data to address the causes of machine failures, proactive maintenance can help prevent equipment failures, resulting downtime, and cost (Omega, 2018).

Operator Training

The operators at the San Felipe plant must be trained to detect and fix any problem that commonly occurs at the plant. Operators at both the Taos and Santa Fe WWTPs have been trained to detect and fix problems with any device at their respective plants. The operators at the San Felipe plant have not developed the expertise on every device on the plant floor (di Ruggiero, personal communication). If something goes wrong where an operator does not have the knowledge to fix a broken device, a technician is called in to fix the problem. However, if the operators at San Felipe were trained to detect and fix problems with not only some, but all devices, then the technician would not be called in as often. This will also help the operators focus on running the San Felipe WWTP as efficiently as possible.

Data Collection System

Each operator must be trained on the Survey123 form we created. This data collection system allows operators to collect data directly from the devices, independent of whether or not the SCADA is accurately reporting data. The form uses QR codes to ensure that the operators collect the correct data for each device. It also contains a comments section for each device. The comments section allows operators to record observations other than reading values, such as whether or not the devices are operating correctly, what maintenance was done on the device, and any other problems with the device, such as rust or leaks. To ensure that operators actually walk the plant floor, the collection system pins the location of where data was collected.

While collecting data using the Survey123 from, we recommend that the operators read the data from each device and the SCADA system to determine if either a certain device or the SCADA system is reporting incorrect data. If there is a discrepancy between the data from the device and the SCADA system, we recommend that the operators bring in a technician to calibrate the system.

IoT at the San Felipe WWTP

The San Felipe WWTP should adopt IoT for the purpose of data collection and analysis. Many operations companies, like SKM, are using IoT to provide both operators and engineers with more data (Rogers, personal communication). Anytime operators or engineers have more data, they can make more informed decisions as to how to run the plant. More informed decisions allow plants to save money on power, chemicals and repairs (Rogers, personal communication).

San Felipe should replace its current PLC with one using IoT; specifically, we recommend Groov EPIC by Opto22. The Groov EPIC is a browser-based controller that uses edge computing to process and utilize data (Orman, personal communication). Edge computing is when data is processed at the "edge" of the network, as opposed to in a centralized location, such as the cloud or a data center (What is Edge Computing?, 2018). Groov EPIC performs the same functions as a PLC using edge computing (Orman, personal communication). Edge computing allows data to be processed and utilized more quickly because the data does not need to be sent to a centralized unit to be processed. When information is processed at the edge of the network, less data has to be sent to the centralized system. This allows data to be processed and used more quickly, allowing the control system to make changes to the system more quickly (What is Edge Computing?, 2018). Edge computing also allows for more reliable data collection: as data is processed locally, devices that operate using edge computing will continue to operate, even in the event of a system failure (Gyarmathy, 2018). This means that if an issue were to arise in the SCADA, the system would be able to operate because the data is processed at the "edge", and not in the SCADA.Groov EPIC can be used for data visualization and alerts. The controller can send alerts to operators and engineers through email or SMS text message (Groov Box User's Guide, 2018). Groov EPIC's data visualization can be optimized based on the specific needs of the plant. Operators can determine what data they want displayed, and how they want it to be displayed (Groov Box User's Guide, 2018). For a plant with 60 points of I/O (input/output), Groov EPIC typically costs about $3700, which includes the controller, power supply, chassis, and any other hardware necessary (Orman, personal communication). The product has a service life of 10-15 years, even in an industrial setting (Orman, personal communication).

Given that the San Felipe WWTP already needs to replace its current PLC, the plant should upgrade to the Groov EPIC. Groov EPIC will allow the control system to make changes and control operations more quickly. This reduces the amount of time required to make changes to plant operations, allowing the plant to operate more efficiently. Edge processing allows more valuable data to be sent to the SCADA, while eliminating unnecessary data. The customizable data visualization will allow operators to determine what data they want, and what data is not necessary. Groov EPIC is a web-based system, which allows operators and engineers to view data and receive alerts at any time, from anywhere.

Based on the research conducted throughout the course of this project, we believe that the San Felipe WWTP would benefit greatly by adopting our Survey123 data collection system and the policies described in our strategic plan. We have determined that the San Felipe plant does not operate at an optimal level of efficiency. We believe that our recommendations will allow the plant to operate more efficiently.

Conclusion

The purpose of this project was to assist Souder, Miller and Associates in the development of strategies that can be used to improve operations at the San Felipe WWTP. We hope our recommendations will be applied to the San Felipe plant to improve efficiency. We also completed the project with the intention that our work will be used in other treatment plants owned by Souder, Miller and Associates.

5. References

Afifi, M., Abdelkader, M. F., & Ghoneim, A. (2018). An IoT system for continuous monitoring and burst detection in intermittent water distribution networks. Paper presented at the 240-247. 10.1109/ITCE.2018.8316632 Retrieved from http://ieeexplore.ieee.org/document/8316632

Alba, M. (2017, May 18). Wastewater Treatment with the Internet of Things. Retrieved September 6, 2018, from https://www.engineering.com/IOT/ArticleID/14925/Wastewater-Treatment-with-the-Internet-of-Things.aspx

Ali, Z. (2014, June 4). Why We Preferrably Use 4-20mA Over 0-10V & 0-20mA As A Analog Signal? Retrieved September 11, 2018, from http://instrupc.blogspot.com/2014/06/why-we-preferrably-use-4-20ma-over-0_4.html

Bank, E. (2017, April 24). How Does a WasteWater Treatment Plant Work? Retrieved March 22, 2018, from https://sciencing.com/waste-water-treatment-plant-work-4896800.html

Breivold, H.P. and Sandström, K., 2015, December. Internet of Things for Industrial Automation--Challenges and Technical Solutions. In Data Science and Data Intensive Systems (DSDIS), 2015 IEEE International Conference on (pp. 532-539). IEEE.

Brown and Caldwell. (2007). *Wastewater Treatment Plant Facilities Plan Update*[PDF]. Newberg, Oregon: Oregon Department of Environmental Quality.

Chandrappa, S., Dharmanna, L., Shyama Srivatsa Bhatta, U. V., Sudeeksha Chiploonkar, M., Suraksha, M. N., & Thrupthi, S. (2017, April). *Design and Development of IoT Device to Measure Quality of Water.* Retrieved September 6, 2018, from MECS Press. doi:10.5815/ijmecs.2017.04.06

Emaint. (n.d.). What is a Work Order? Retrieved September 24, 2018, from https://www.emaint.com/works/what-is-a-work-order/

Environmental Protection Agency. (n.d.). Epa.gov. Retrieved. March 28, 2018, from https://www.epa.gov/compliance/clean-water-act-cwa-compliance-monitoring

EPA. (2018, January 30). The Sources and Solutions: Wastewater. Retrieved from https://www.epa.gov/nutrientpollution/sources-and-solutions-wastewater

ERPortal. (n.d.). Asset and Maintenance Management Software. Retrieved September 24, 2018, from http://www.erportalsoftware.com/products/enterprise-asset-management-software.asp

Esri. (n.d.). Esri: GIS Mapping Software, Spatial Data Analytics & Location Platform. Retrieved October 9, 2018, from https://www.esri.com/en-us/home

Fiix. (n.d.). CMMS Features, Information, and Overview | Fiix . Retrieved October 1, 2018, from https://www.fiixsoftware.com/cmms/features/#prevenativemaint

Fuller, J. (2018, September 28). How to design an IoT-ready infrastructure: The 4-stage architecture. Retrieved October 9, 2018, from https://techbeacon.com/4-stages-iot-architecture

Gilchrist, A., (2016). *Industry 4.0: the industrial internet of things*. Apress.

Gold, J. (2018, February 02). *What is the Industrial IoT? [And why the stakes are so high]*. Retrieved September 6, 2018, from https://www.networkworld.com/article/3243928/internet-of-things/what-is-the-industrial-iot-and-why-the-stakes-are-so-high.html

Groov Box User's Guide. (2018, August). Retrieved October 5, 2018, from http://documents.opto22.com/2104_groov_Box_Users_Guide_for_GROOV-AR1.pdf

Gyarmathy, K. (2018, July 19). The 5 Best Benefits of Edge Computing. Retrieved October 9, 2018, from https://www.vxchnge.com/blog/the-5-best-benefits-of-edge-computing

Harrington, L., P.E, McCoy, G., Joiner, M., Williams, C., P.E, Carter, M., & Williamson, T. (2014, May). *WWTP Operations and Maintenance Program* [PDF]. Jackson, Mississippi: Department of Public Works.

Hunzinger, R. (2016). SCADA Fundamentals and Applications in the IoT. *Internet of Things and Data Analytics Handbook,*283-293. doi:10.1002/9781119173601.ch17

Li, Y., Arnold, S. D., Kozel, C., & Forster-Cox, S. (2005). Water availability and usage on the New Mexico/Mexico border. Journal of Environmental Health, 68(3), 10-7, 32. Retrieved from http://ezproxy.wpi.edu/login?url=https://search.proquest.com/docview/219706904?accountid=29120

Lobo, W. (2017). Ways to improve water treatment plant efficiency. *World Pumps,2017*(9), 32-33. doi:10.1016/s0262-1762(17)30297-3

Meola, A. (2016, December 19). What is the Internet of Things (IoT)? Retrieved from http://www.businessinsider.com/what-is-the-internet-of-things-definition-2016-8

Miorandi, D., Sicari, S., De Pellegrini, F., & Chlamtac, I. (2012). Internet of things: Vision, applications and research challenges. *Ad hoc networks*, *10*(7), 1497-1516.

New Mexico Environment Department. (n.d.). *Liquid Waste Program*. Retrieved April 05, 2018, from https://www.env.nm.gov/liquid_waste/laws-and-regulations/

New Mexico Environment Department. (2007). *New Mexico Wastewater Systems Operator Certification Study Manual*[PDF]. Santa Fe, New Mexico.

Omega. (2018, September 05). Reactive Maintenance vs. Proactive Maintenance: You're Paying 2-5X More for Maintenance. Retrieved September 16, 2018, from https://www.omega.com/technical-learning/Proactive-Maintenance-vs-Reactive-Maintenance.html

Park, J. (2016). *Wastewater Treatment Processes*. Presentation, University of Wisconsin-Madison.

Rambus. (n.d.). Industrial IoT: Threats and Countermeasures. Retrieved April 18, 2018, from https://www.rambus.com/iot/industrial-iot/

R. F. Wireless World (2012). Advantages of SCADA System | disadvantages of SCADA System. Retrieved April 28, 2018, from http://www.rfwireless-world.com/Terminology/Advantages-and-Disadvantages-of-SCADA.html

Richardson, K. (2018, July 9). Esri Announces New Indoor Mapping Product. Retrieved September 11, 2018, from http://www.esri.com/esri-news/releases/18-3qtr/esri-announces-new-indoor-mapping-product

Rouse, M. (n.d.). What is control system? - Definition from WhatIs.com. Retrieved April 12, 2018, from https://whatis.techtarget.com/definition/control-system

Rouse, M., & Aberle, L. (2015, March). What is Industrial Internet of Things (IIoT)? - Definition from WhatIs.com. Retrieved April 29, 2018, from https://internetofthingsagenda.techtarget.com/definition/Industrial-Internet-of-Things-IIoT

Serpanos, D. and Wolf, M., 2018. Industrial Internet of Things. In Internet-of-Things (IoT) Systems (pp. 37-54). Springer, Cham.

Shoja, S. and Jalali, A., 2017, December. A study of the Internet of Things in the oil and gas industry. In Knowledge-Based Engineering and Innovation (KBEI), 2017 IEEE 4th International Conference on (pp. 0230-0236). IEEE.

SMA Operations LLC. (2018). Retrieved April 28, 2018, from http://smaopsllc.com/

Survey123 for ArcGIS. (2018). Retrieved from https://survey123.arcgis.com/

Turcu, C., Turcu, C., & Gaitan, V. (2012). *Advances in computer science: Proceedings of the 6th WSEAS European computing conference (ECC12): Prague, Czech Republic*, September 24-26, 2012. WSEAS Press. Retrieved September 6, 2018, from https://pdfs.semanticscholar.org/cde5/0df4bd885ec3224747e84b65bb77d96263f5.pdf.

Turner, J. D. (2002, June). *Shelby SOP: Wastewater Treatment Division Maintenance* [PDF]. Shelby: City of Shelby Department of Utility.

Vermesan, O., & Friess, P. (Eds.). (2012). *Internet of things: converging technologies for smart environments*. Retrieved from https://ebookcentral-proquest-com.ezproxy.wpi.edu

Walker, L. (2017, December 26). 11 Ways CMMS Benefits Your Organization. Retrieved September 28, 2018, from https://www.betterbuys.com/cmms/11-cmms-benefits/

Wang S, Zhang Z, Ye Z, Wang X, Lin X, Chen S. Application of environmental internet of things on water quality management of urban scenic river. International Journal of Sustainable Development & World Ecology. 2013;20(3):216-222. https://www-tandfonline-com.ezproxy.wpi.edu/doi/full/10.1080/13504509.2013.785040. Accessed Mar 19, 2018. doi: 10.1080/13504509.2013.785040.

Water and Waste Digest. (n.d.). SCADA Optimizes Plant Performance. Retrieved from https://www.wwdmag.com/software-process-control/scada-optimizes-plant-performance

What is Edge Computing? (2018, August 08). Retrieved from https://www.cbinsights.com/research/what-is-edge-computing/

Wootton, J. (2013). Image gallery for work done on the Woodlake Waste Water Treatment Plant (WWWTP) using Ignition SCADA. Retrieved September 11, 2018, from http://jwintegration.com/gallery_ignition.htm

Yang, S. H. (2014). Internet of things. In *Wireless Sensor Networks* (pp. 247-261). Springer, London.

Yates, S. (n.d.). What Does a Good Strategic Asset Management Plan Look Like? Retrieved September 10, 2018, from https://www.assetivity.com.au/article/asset-management/what-does-a-good-strategic-asset-management-plan-look-like.html

Zadorojniy, A. (2016, August 22). How we used IoT data to optimize wastewater treatment - IBM Blog Research. Retrieved September 6, 2018, from https://www.ibm.com/blogs/research/2016/08/used-iot-data-optimize-wastewater-treatment/

Appendix A: Table of Devices and Photos

Type of Device	Model	Production	Alternative Device	Photo	Source
Flow Meters	ABB MagMaster	Discontinued	CoriolisMaster FCB430 and FCB450 from ABB Price: $3,000		https://new.abb.com/products/measurement-products/flow/coriolis-mass-flowmeters/coriolismaster-fcb400-coriolis-mass-flowmeter https://www.alibaba.com/product-detail/CoriolisMaster-FCB430-FCB450-Coriolis-Mass-Flowmeter_60766929669.html
Sewage Lift Pump Stations	KSB	N/A	Ama-Porter CK-Pumpstation	N/A	Called regional distributor Alpha Southwest on Sep. 27, need more data on the pump- serial number
Influent & Effluent Sampler	Sigma Aldrich	N/A	SPME Portable Field Sampler coating Polydimethylsiloxane (PDMS) from Sigma Price: $373	N/A	https://www.sigmaaldrich.com/catalog/product/supelco/504823?lang=en&region=US
Spiral Screen	WesTech Cleanflo Spiral Screen	In production Price not available.	N/A	N/A	Emailed manufacturer sales representative on Sep 14

Blowers	Neuros NX100	Discontinued	NX100-C $106,750		Called manufacturer on September 26, manufacturer will send more information, We called them again and left a message on Oct. 1, Received quote from manufacturer on Oct. 4
Membrane Basins	Enviroquip/ Kubota	N/A	Ovivo Membrane Bioreactor Systems (MBR) Price: $9/gal	N/A	https://www.ovivowater.com/product/municipal/municipal-wastewater/aerobic-treatment-nutrient-removal/mbr/ovivo-mbr/
Permeate Pumps	Gorman-Rupp T-Series	In Production	N/A	N/A	Called regional distributor James Cooke and Hobson on Sep. 27. Need serial number and pump specifications
UV Unit	Wedeco LBX-200	In Production $70,000	N/A	N/A	Called manufacturer three times- Sep 26, Sep 27, Oct 1, received message on Oct. 5

Utility Water Pumps	Grundfos	N/A	N/A	N/A	Called regional distributor: Alpha Southwest on Sep. 26, need more data on the pump- serial number
Sludge Pump	BDP BN 15-6LT	In production $20,000	N/A	N/A	Called manufacturer on Sep. 26 and Oct. 2
Belt Filter Press	BDP 0.9 M DDP	In production $255,000	N/A		Called manufacturer on Sep. 26 and Oct. 2
Polymer Blending System	Fluid Dynamics	N/A	N/A	N/A	Called manufacturer on Sep. 27, need more information- serial number
Cake Pump	BDP BT 5-12	In production $25,000	N/A	N/A	Called manufacturer on Sep. 26 and Oct. 2
Turbidity Meter	Missing	N/A	N/A	N/A	N/A

Microprocessor Dosing Pump	LMI Milton Roy A series	Discontinued	B-series		Emailed manufacturer on Sep. 26 and local distributor on Sep 27, could not get price because we do not have the necessary information
Gas Monitor	MSA Ultima	In Production Price not available	N/A		Emailed manufacturer on Sep 24, must submit order form for pricing

Appendix B: QR Codes

QR Code	Text Encoded
	L10_Train1Flux/Flux/Output
	L10_Train1Permeability/Permeability/Output
	L10_Train1TMP/TMP/Output
	L100_LiftStationLevel/Level/Output

	L110_LiftPump1/Current/Output
	L110_LiftPump1/Speed/Output
	L120_LiftPump2/Current/Output
	L120_LiftPump2/Speed/Output

	L200_InfluentFlow/Flow/Output
	L200_InfluentFlow/FlowTotal/TodaysFlow
	L200_InfluentFlow/FlowTotal/TotalFlow
	L200_InfluentFlow/FlowTotal/YesterdaysFlow

	L210_Screen1FrontLevel/Level/Output
	L220_Screen2FrontLevel/Level/Output
	L231_LEL/Level/Output
	L232_H2SGas/Level/Output

	L310_AnoxicBasin1TSS/TSS/Output
	L311_AnoxicBasin1DO/DO/Output
	L311_AnoxicBasin1Temperature/Temperature/Output
	L330_RecycleBasinLevel/Level/Output

	L410_AnoxicBasin2TSS/TSS/Output
	L411_AnoxicBasin2DO/DO/Output
	L411_AnoxicBasin2Temperature/Temperature/Output
	L500_Train1PermeatePressure/Pressure/Output

	L510_PermeatePump1/Current/Output
	L510_PermeatePump1/Speed/Output
	L510_PermeatePump1Flow/Flow/Output
	L510_PermeatePump1Flow/FlowTotal/TodaysFlow

	L510_PermeatePump1Flow/FlowTotal/TotalFlow
	L510_PermeatePump1Flow/FlowTotal/YesterdaysFlow
	L511_PermeatePump2/Current/Output
	L511_PermeatePump2/Speed/Output

	L511_PermeatePump2Flow/Flow/Output
	L511_PermeatePump2Flow/FlowTotal/TodaysFlow
	L511_PermeatePump2Flow/FlowTotal/TotalFlow
	L511_PermeatePump2Flow/FlowTotal/YesterdaysFlow

	L530_PermeateTurbidity/Turbidity/Output
	L600_UV1Intensity/Intensity/Output
	L601_UV2Intensity/Intensity/Output
	L610_StorageTank/Level/Output

	L620_UtilityWaterPressure/Pressure/Output
	L630_ChemicalCleanFlow/Flow/Output
	L630_ChemicalCleanFlow/FlowTotal/TodaysFlow
	L630_ChemicalCleanFlow/FlowTotal/TotalFlow

	L630_ChemicalCleanFlow/FlowTotal/YesterdaysFlow
	L631_UtilityWaterFlow/Flow/Output
	L631_UtilityWaterFlow/FlowTotal/TodaysFlow
	L631_UtilityWaterFlow/FlowTotal/TotalFlow

	L631_UtilityWaterFlow/FlowTotal/YesterdaysFlow
	L730_BlowerDischargePressure/Pressure/Output
	L730_BlowerDischargeTemperature/Temperature/Output
	L730_BlowerFlowtoAeration/Flow/Output

	L730_MembraneAirControlValvePosition/Position/Output
	L731_BlowerFlowtoMembranes/Flow/Output
	L800_WasteFlow/Flow/Output
	L800_WasteFlow/FlowTotal/TodaysFlow

	L800_WasteFlow/FlowTotal/TotalFlow
	L800_WasteFlow/FlowTotal/YesterdaysFlow
	PlantFlowMode

Appendix C: Questions for Participants in Testing Survey Usability and Functionality

1. On a scale of 1-5 (1 being the worst, 5 being the best) how would you rate the user-interface of the form (circle one)?

1 2 3 4 5

2. If you could change one thing about the form what would you change?

____

____

____

3. What part of the form did you find most intuitive?

____

____

____

4. Were there any specific parts that were confusing?

____

____

____

Informed Consent for Participants in Testing Survey Usability and Functionality

Investigators: Michael Nardo, Sebastien Casimir, Jack Haddad, and Ethan Peters
Contact Information: mcnardo@wpi.edu, scasimir@wpi.edu, ewpeters@wpi.edu, jghaddad@wpi.edu
Title of Research Study: IoT at the San Felipe Wastewater Treatment Plant
Sponsor: Souder Miller and Associates

Introduction
You are being asked to participate in a research study. We would like you to test out our Survey123 form to determine if the form is user-friendly. This form will be used at the San Felipe WWTP.

Purpose of the study: The goal of this project is to assist Souder, Miller and Associates in the development of strategies that can be used to improve operations at the San Felipe WWTP.

Procedures to be followed: Subjects will test our Survey123 form and scan QR codes.We will then interview subjects to determine if the Survey123 form we created is user-friendly.

Benefits to research participants and others: They can work with an updated system for the San Felipe WWTP.

Record keeping and confidentiality: We plan to document the interview by writing down the answers to our questions. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

By signing below, you acknowledge that you have been informed about and consent to be a participant in the study described above. Make sure that your questions are answered to your satisfaction before signing. You are entitled to retain a copy of this consent agreement.

______________________________ Date: ____________________
Study Participant Signature

____
Study Participant Name (Please print)

Appendix D: Interview with other WWTPs

Investigators: Michael Nardo, Sebastien Casimir, Jack Haddad, and Ethan Peters
Contact Information: mcnardo@wpi.edu, scasimir@wpi.edu, ewpeters@wpi.edu, jghaddad@wpi.edu
Title of Project: IoT at the San Felipe Wastewater Treatment Plant
Sponsor: Souder Miller and Associates

Introduction
You are being asked to participate in an interview. We ask that the answers you provide us be as detailed as possible. Your responses will be integrated into our project.

Purpose of the interview: The goal of this project is to assist Souder, Miller and Associates in the development of strategies that can be used to improve operations at the San Felipe WWTP.

Procedures to be followed: We will ask the interviewee a series of questions and the responses we get will be used to assist our group in our project. We will asked the interviewee if we could record the interview and they can choose whether or not they want to be recorded.

Record keeping and confidentiality: We plan to document the interview by writing down the answers to our questions. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

1. What specific training does each employee receive?
2. Have you implemented IoT in your plant?
3. How do you determine which devices or machines need to be replaced or repaired?
4. Do you find that devices often need to be replaced, or can they be fixed without replacing the entire unit?
5. Have you developed a preventive/proactive maintenance schedule?
6. If so, how did you develop a proactive maintenance schedule?
7. Does your plant have emergency replacement parts for your devices in case something goes wrong?
8. Do you find that operators can make better decisions with more data?
9. Do you use an open source SCADA or PLC?
    a. If so, how has that changed plant operations?

Appendix E: Interview with SKM Engineering

Investigators: Michael Nardo, Sebastien Casimir, Jack Haddad, and Ethan Peters
Contact Information: mcnardo@wpi.edu, scasimir@wpi.edu, ewpeters@wpi.edu, jghaddad@wpi.edu
Title of Project: IoT at the San Felipe Wastewater Treatment Plant
Sponsor: Souder Miller and Associates

Introduction
You are being asked to participate in an interview. We ask that the answers you provide us be as detailed as possible. Your responses will be integrated into our project.

Purpose of the interview: The goal of this project is to assist Souder, Miller and Associates in the development of strategies that can be used to improve operations at the San Felipe WWTP.

Procedures to be followed: We will ask the interviewee a series of questions and the responses we get will be used to assist our group in our project. We will asked the interviewee if we could record the interview and they can choose whether or not they want to be recorded.

Record keeping and confidentiality: We plan to document the interview by writing down the answers to our questions. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

1. How have you implemented IoT in WWTPs for data collection and analysis?
2. What devices or systems needed to be changed or replaced to implement IoT?
3. Has IoT helped plant operators to obtain more data?
4. If so, has this led to plant operations becoming more efficient or cost effective?
5. How could IoT reasonably be implemented at San Felipe given the current operations?
6. Do you have a list of devices that are currently at the San Felipe plant?
    a. Does the list of devices at the San Felipe plant prioritize each device?
7. Do you have any recommendations for upgrades to the devices in the San Felipe plant?
    a. How would you go about finding replacements for devices that have been discontinued?

Appendix F: Interviews with IoT system manufacturers

Investigators: Michael Nardo, Sebastien Casimir, Jack Haddad, and Ethan Peters
Contact Information: mcnardo@wpi.edu, scasimir@wpi.edu, ewpeters@wpi.edu, jghaddad@wpi.edu
Title of Project: IoT at the San Felipe Wastewater Treatment Plant
Sponsor: Souder Miller and Associates

Introduction
You are being asked to participate in an interview. We ask that the answers you provide us be as detailed as possible. Your responses will be integrated into our project.

Purpose of the interview: The goal of this project is to assist Souder, Miller and Associates in the development of strategies that can be used to improve operations at the San Felipe WWTP.

Procedures to be followed: We will ask the interviewee a series of questions and the responses we get will be used to assist our group in our project. We will asked the interviewee if we could record the interview and they can choose whether or not they want to be recorded.

Record keeping and confidentiality: We plan to document the interview by writing down the answers to our questions. Records of your participation in this study will be held confidential so far as permitted by law. However, the study investigators, the sponsor or it's designee and, under certain circumstances, the Worcester Polytechnic Institute Institutional Review Board (WPI IRB) will be able to inspect and have access to confidential data that identify you by name. Any publication or presentation of the data will not identify you.

1. Which product(s) have the most promising use in a WWTP?
2. What does the product do, and how does is operate?
3. Is the product compatible with Ignition?
4. How does the product connect to sensors?
5. Does the product use open source or proprietary software?
6. What is the price of the product?
7. What is the lifetime of the product?
8. Is this product suitable for the corrosive environment of a WWTP?

Appendix G: Test Participant Responses

Some responses were omitted from this document for being unhelpful or nonspecific.

On a scale of 1-5 (1 being the worst, 5 being the best) how would you rate the user-interface of the form (circle one)?

- Four people responded with a 2.
- Five people responded with a 3.
- Two people responded with a 4.

Average score of 2.8

If you could change one thing about the form what would you change?

- The QR code scanning ability of the form
- It is a little confusing about where one part begins and ends.
- It would help if the QR codes had clearer/more distinct names
- Some more instructions on what info you are looking for
- The naming convention for devices
- Have one device entry per survey submission
- The names and fill boxes were unclear. Make them more grouped so I know which fill in section belonged to which title – the names were a little confusing

What part of the form did you find most intuitive?

- When the camera had a camera button to take a picture
- QR code reader
- Scanning QR codes and taking pictures of data
- The QR code
- The submitting process
- Scanning QR codes is intuitive
- QR code scanner
- The QR code
- Scanning the QR code
- The QR codes
- QR codes, camera

Were there any specific parts that were confusing?

- Which question/part of question needed what data/image

- Maybe having an expandable instruction thing for each part
- Confusing when scanning the wrong QR code
- What numbers to report
- Needing to scan specific qr code into specific fields was confusing and counterintuitive
- The names of the devices, the list of devices
- Scrolling through a list to find the device and submitting information on just some of the survey devices
- The naming was confusing
- No separation between sections